LANDFIRE

Study Plan

For the

Prototype Areas

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Department of Agriculture
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Rocky Mountain Research Station
Fire Science Laboratory

Department of the Interior
Geological Survey
EROS Data Center

A Joint Project between USDA Forest Service and Department of the Interior US Geological Survey, Bureau of Land Management, National Park Service, Bureau of Indian Affairs, and Fish and Wildlife Service.

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INTRODUCTION

Over ninety years of fire exclusion (Pyne 1982), domestic livestock grazing, logging, and widespread exotic species invasions have altered fire regimes, fuel loadings, and vegetation composition and structure (Barrett and others 1991, Brown and others 1994, Ford and McPherson 1999, West 1994, Whisenant 1990). As a result, the number, size, and intensity of wildfires have significantly changed from the historical conditions (US GAO 1999, Vail 1994), sometimes with catastrophic consequences. Recent examples of this include the Cerro Grande fire of 2000 that burned over 235 homes in Los Alamos, New Mexico; the 8,422,237 acres burned in the western United States (US) during the 2000 fire season; and the Thirtymile fire of 2001 that killed four fire fighters in Washington on the Okanogan-Wenatchee National Forest.

In response to these changing conditions, the President directed the Secretaries of Agriculture and the Interior to develop a report that recommends how best to: respond to severe wildland fires, reduce fire impacts on rural communities, and ensure sufficient firefighting capacity in the future (USDA FS and US DOI 2000). Congress in turn mandated the implementation of the National Fire Plan in the 2001 Interior and Related Agencies Appropriations Act. The National Fire Plan (USDA FS and US DOI 2002), a Congressional directive, is a long-term investment that will help protect communities and natural resources, and most importantly, the lives of fire fighters and the public. It is a long-term commitment based on cooperation and communication among federal agencies, states, local governments, tribes, and interested publics. Key points in the National Fire Plan are:

1) Firefighting – Ensure adequate preparedness for future fire seasons.
2) Rehabilitation and Restoration – Restore landscapes and rebuild communities damaged by wildfire.
3) Hazardous Fuels Reduction – Invest in projects to reduce risk.
4) Community Assistance – Work directly with communities to ensure adequate protection.
5) Accountability – Be accountable and establish adequate oversight and monitoring for results.

The National Fire Plan advocates a new approach to wildfires by shifting emphasis from reactive to proactive – from attempting to suppress wildland fires to reducing the buildup of hazardous vegetation that fuels severe fires (US GAO 2002). The Plan recognizes that, unless hazardous fuels are reduced, the number of severe wildland fires and the cost associated with suppressing them will continue to increase (US GAO 2002). Reducing the buildup of hazardous vegetation that fuels severe fires requires a strategic plan for vegetation management by federal land mangers (US GAO 2002, USDA FS 2000).

In order to develop a strategic framework for the National Fire Plan, the United States Department of Agriculture (USDA) Forest Service (FS) and Department of Interior (DOI) are jointly writing a "Cohesive Strategy" to reduce fuels and restore land health in fire-prone areas. The strategy is intended to:

1) Improve the resilience and sustainability of forest and grasslands at risk.
2) Conserve priority watersheds, species, and biodiversity.
3) Reduce wildland fire costs, losses, and damages.
4) Better ensure public and firefighter safety.

An early version of the strategy stated that the optimum method to ensure success in restoring ecosystems is collaborating with the local planning efforts (USDA FS 2000). These efforts will need to integrate specific concerns and priorities at a watershed or landscape scale within the context of regional and national plans (USDA FS 2000). This will require multi-scale spatial data – spatial data that provides appropriate information at all scales (i.e., local, regional, and national). This data is critical for federal land managers to prioritize, plan, and allocate dollars and resources need to accomplish the Strategy's objectives described above.

Unfortunately, federal land management agencies do not have adequate data for making informed decisions and measuring the agencies' progress in reducing fuels (US GAO 2002). A recent General Accounting Office (GAO) report (US GAO 2002) revealed that *"The infusion of hundreds of millions of dollars of new money for hazardous fuel reduction activities for fiscal years 2001 and 2002 and the expectation of sustained similar funding for these activities in future fiscal years accentuate the need for accurate, complete, and comparable data."* The report emphasized three main points on data needs. 1) Federal land agencies need data to better identify and prioritize wildland-urban interface communities within the vicinity of federal lands that are at high risk from wildland fires. 2) Federal land agencies need to collect adequate data to expedite the project-planning process, which requires complying with numerous environmental statutes addressing individual resources, such as endangered and threatened species, clean water, and clean air. 3) Federal land agencies need data to measure the effectiveness of efforts to dispose of the large amount of brush, small trees, and other vegetation that must be removed to reduce the risk of severe wildland fire (US GAO 2002).

In order to implement the National Fire Plan and Cohesive strategy, federal land management agencies need collect accurate, complete, and comparable data for prioritizing, planning, monitoring, and allocating dollars and resources (US GAO 2002). This data will provide the appropriate information at the appropriate scale for fire management. Unfortunately, creating this spatial data by land managers is difficult. Extensive knowledge and experience in fire ecology, Geographic Information System (GIS) techniques, remote sensing, and image processing is needed to create the maps required by the National Fire Plan. This knowledge and experience may not be found at local agency offices. Also, local offices seldom have the complex computer hardware and software resources required for this task. Lastly, independent local mapping efforts may not scale upwards to the national level or match adjacent mapping efforts, thus limiting their application.

The objective of this project – called LANDFIRE – is to provide the spatial data and predictive models needed by land and fire managers to prioritize, evaluate, plan, complete, and monitor fuel treatment and restoration projects, essential to achieving the goals targeted in the Cohesive Strategy and National Fire Plan. These spatial data and predictive models will be hierarchically designed so that they can be used for various levels of management, from the national level (coarse scale) to the local level (fine scale). These products are needed to support the step-down planning process, which is considered to be the cornerstone in integrating landscape scale projects with ecological and socio-economic objectives (Hann and others 1988, Quigley and others 1996). The LANDFIRE products can be broken into three main groups: 1) maps that characterize vegetation and fire regimes, 2) maps that characterize fuel conditions, and 3) maps and models used to evaluate ecosystem status and fire hazard and potential status.

LANDFIRE will create maps that characterize vegetation, historical natural fire regimes, and departures of historical natural fire regimes, known as fire regime condition classes. These maps can be used to prioritize areas for hazardous fuel reductions projects while evaluating rehabilitation and restoration objectives. They can also be used to reduce wildfire costs, losses, and damages by prioritizing communities within the vicinity of federal lands that are at high risk from wildland fires. To create these maps, we will build on the scientific methods used by (Hardy and others 2001), who developed several of these maps at a coarse scale resolution (1-kilometer pixel size) for the lower 48 states. These coarse scale maps provided valuable information for prioritization and planning at a national level, but fell short in providing information at the regional and local level because of the coarseness of the data (Schmidt and others 2002). By incorporating the latest scientific methods we will be able to develop these maps at the mid to fine scale resolution (30 meter pixel size) (Keane and others 2003, Rollins and others 2003).

LANDFIRE will also create a series of maps that characterize fuel conditions based on fire behavior (Andrews 1986), fire effects (Reinhardt and Keane 1998) , and fire danger (Bradshaw and others 1993) research. For example, fuel models and fuel loading maps could be used in fire spread simulation models like FARSITE to support firefighting. Fire effects maps that characterize fuel conditions (i.e., fuel consumption, tree mortality, and soil heating) could be used to prioritize and evaluate rehabilitation and restoration project. Lastly, fire danger maps (i.e., burning index, spread component, and energy release components) could be used to prioritize and evaluate hazardous fuel reduction projects. Most of the maps used to characterize fuel conditions will come from the FIREHARM model developed for LANDFIRE.

LANDFIRE will also develop a series of succession models that will be used to evaluate ecosystem status and fire hazard and potential status (Keane and others 1996, Keane and others 2002b). These evaluations will be based on comparisons from historical conditions (i.e., pre-European settlement) to present conditions. Ecosystem status will be based on ecological characteristics such as species compositions, vegetation structure and landscape metrics. Fire hazard and potential status will be based on fuel characteristics such as crown fire potential, flame length and fuel consumptions. By comparing historical conditions to current conditions, we can evaluate the historical range and variability of landscape patterns and characteristics useful to managers in planning and designing landscape treatments (Parsons and others 1999, Landres and others 1999) This information can also be used to complying with numerous environmental statutes addressed in the GAO a report described above.

This study plan is intended to be the working document for developing these important products. The main body of this document is intended to provide the flow, descriptions, and general methods of the major tasks required to complete this complex project. Since many of methods are individual research projects, we will use the appendices to provide detail descriptions, methods, and eventually results. The appendices will be updated through out the life of the project, with the current updates available on the web (www.landfire.gov). In this study plan we will first describe the scope of this project in the LANDFIRE OVERVIEW section, then we will briefly review the science that is the foundation for the project in the BACKGROUND section, before getting into the details in the METHOD section.

LANDFIRE OVERVIEW

LANDFIRE is a multi-scale fire, ecosystem, and fuel assessment-mapping project designed to generate comprehensive, wall-to-wall, high resolution maps of vegetation, fire, and fuel characteristics across the conterminous US. The project will produce a comprehensive package of spatial data layers, models, and tools that will support the analyses required for prioritization and planning at national, regional, and local scales. The project is targeted to provide federal land agencies the data required to fulfill the goals in the National Fire Plan and Cohesive Strategy. LANDFIRE is a joint multi-agency project between USDA FS and DOI Geological Survey, Bureau of Land Management, National Park Service, Bureau of Indian Affairs, and Fish and Wildlife Service, with the principle investigators located at the USDA FS Rocky Mountain Research Station Fire Science Laboratory and DOI Geologic Survey EROS Data Center. The project was initialized by a request from federal land agencies to the principle investigators asking them to develop the maps needed to prioritize areas for hazardous fuel reduction.

In order to complete this ambitious task of creating high-resolution maps of vegetation, fire, and fuel characteristics for the conterminous US, we will first explore and evaluate different methods on two prototype areas (these locations are described in the PROTOTYPE section below). These methods will be based on the best science and data available for the conterminous US, and will be described in the BACKGROUND and METHODS sections below. The results of the prototype effort will then be applied to map the conterminous US using efficient, affordable, and repeatable procedures. This study plan describes the methods we will use in the prototype effort. The project is based on the following specifications and general product descriptions.

1) LANDFIRE will create spatial data and predictive models needed by federal land agencies to achieve the goals in the National Fire Plan and Cohesive Strategy. The deliverable for the project can be broken into three main groups: 1) maps that characterize vegetation and fire regimes; 2) maps that characterize fuel conditions; and 3) maps and models used to evaluate ecosystem status and fire hazard and potential status. These deliverables will be explained in more detail in the METHODS and DELIVERABLE sections of this study plan.

2) LANDFIRE is designed to be a multi-scale hierarchical project. Spatial data and models developed by the project can be used for various levels of management, from the national level (coarse scale) to the local level (fine scale).

3) LANDFIRE spatial data and models will be created with the same level of detail for all lands and all vegetative communities (forestlands, shrublands, and rangelands) in the conterminous US. This will allow federal land agencies to manage lands independently and jointly.

4) LANDFIRE is designed to be repeatable at various time intervals (e.g., decade) in efficient and affordable manner. This will allow land managers the ability to evaluate changing landscape composition and structures, and to assess the effectiveness of the local land and fire restoration programs.

5) LANDFIRE will be mapped at the mid-scale, targeting map accuracies of 60 to 80 percent for the sub-watershed level (10,000 to 40,000 acres). However, the spatial datasets will be maintained at a 30-meter pixel size, which allows field managers to step down the maps to a fine scale by using the methods, tools, and reference data provide in the project. LANDFIRE is intended to be the safety net for land management agencies that do not have local-scale information. The project is not a substitute for concurrent finer scale mapping efforts at the local level, but is designed to be scalable from sub-watersheds to a national level.

BACKGROUND

LANDFIRE integrates several highly complex methodologies from a few disciplines into a comprehensive process for mapping vegetation, fire, and fuel characteristics. These methodologies are based on many years of successful scientific research projects. They include gradient modeling, remote sensing, successional modeling, and ecological attribute mapping. We will briefly describe each of these methodologies below, but first we will provide a general description of how they will be used in the project.

We will integrate several methodologies to create a suite of maps used to characterize vegetation, fire regimes, and fuels. To characterize vegetation, we will fuse gradient modeling and remote sensing methodologies to create maps of biophysical settings, cover types, and structural stages. To characterize fire regimes, we will link successional modeling and gradient modeling methodologies with the biophysical settings map to create maps of historical natural fire regimes. These maps and models will be integrated with cover type and structural stages to map fire regimes condition class. We will also use successional modeling to create maps that characterize ecosystem status and fire hazard and potential status. To characterize fuels, we will apply ecological attribute mapping methodology by assigning fuel descriptors (i.e., fuel models) to unique combinations of categories created when combining potential vegetation types, cover types, and structural stages maps. These maps, when combined, are also referred to as the vegetative triplet.

Gradient Modeling

Gradient analysis provides a powerful means to describe and classify ecological communities in terms of spatial and temporal environmental gradients (Kessell 1976, 1979). It is often defined as the quantitative description of a plant species along one or more environmental gradient, such as elevation, precipitation, or succession (Keane and others 2002c). Traditionally, ecologists have used the composition and abundance of plant species to identify the environmental gradients important to vegetation classification. However, the same approach can be used to describe other ecosystem characteristics, such as fire regimes. Complex numerical techniques such as ordination, principal components analysis, reciprocal averaging, and canonical correspondence analysis have given ecologists the ability to identify and describe ecological gradients using statistic analyses on plant composition (Gauch 1982, ter Braak 1987). Once the key gradients are identified, they can then be mathematically represented in a **gradient model** to predict changes in species composition, or any other ecosystem characteristics, across a landscape (Kessell 1979, Gosz 1992). For more information about gradient modeling, see (Keane and others 2002c).

There are many advantages of using gradient modeling over other mapping schemes. First, gradients are often scale-independent, flexible and portable (Franklin and Woodcock 1997, Gosz 1992, Whittaker 1975). If gradients are similar in lands outside the sampled areas, the field data can be extrapolated to unsampled areas. Some gradients are static and do not change over time (e.g. topography) so replicated sampling is not necessary. Relationships of ecological characteristics to direct environmental gradients probably won't change in the near future, but the spatial distribution of direct gradients will change. So, maps of future climates can be used with the gradient model to compute distributions of future vegetation complexes (Linder 2000). Lastly, vegetation-gradient relationships will enable resource managers to explore new aspects in landscape ecology and will provide a context in which to understand the effect of human activities on ecological interrelationships (Muller 1998, Nixon 1995).

The real strength of gradient modeling lies in its ability to describe the potential of communities on the landscape to possess a particular ecosystem characteristic, such as cover type or basal area. This information can be used to narrow the range of possibilities for classifications of remotely sensed images to increase accuracy and provide context. Gradient modeling also provides us with a scientific ground approach to map other ecosystem properties, such as fire regimes and fuel conditions, that are important to land and fire management planning (Keane and others 2002c).

Remote Sensing and Image Processing

While gradient modeling is used to predict environmental conditions and potential species composition and structure across a landscape, remote sensing provides a means to derive current vegetation characteristics and current environmental conditions by directly measuring the reflected and/or emitted energy from the land surface. Often designed with a capability to acquire data for the entire globe, satellite remote sensing is especially suitable for monitoring vegetation dynamics over large areas. While wall-to-wall satellite data sets for large areas used to be available only at 1-square kilometer or coarser spatial resolutions (Townshend 1994), they have become increasingly available and affordable at intermediate spatial resolutions. As a result, a number of large area vegetation maps have been successfully developed using such intermediate resolution satellite data (Homer and others 1997, Vogelmann and others 2001b).

Many remote sensing efforts have combined environmental analysis with conventional image processing to create maps of existing vegetation or land cover (see Davis and others 1991). Topographical variables, derived from Digital Elevation Models (DEMs), have long been used to stratify or augment image classification procedures for mapping vegetation attributes (see Fahsi and others 2000, Lieffers and Larkins-Lieffers 1987, Cibula and Nyquist 1987). Miller and Golden (1991) used physiography and Landsat MSS (Multispectral Scanner) imagery to map forest site classifications. Topography, geographic zones, and Landsat MSS imagery with ground data were used to map forest productivity in northwestern California (Fox and others 1985). Georeferenced ecological field data coupled with kriging and imagery were used to analyze ecological patterns at landscape scales in South Carolina (Michener and others 1992). Bolstad and Lillesand (1992) used soils and terrain to map forest vegetation in Wisconsin, but He and others (1998) improved on their methods by integrating FIA (Forest Inventory and Analysis) plot inventory data with GIS layers of regional ecosystem classification, climate, and soils to map dominant species in northern Wisconsin. Shao and others (1996) used potential vegetation types derived from soils and topography to refine a cover type classification from satellite imagery for a natural reserve in China. A major problem with many of these efforts is that the field reference data were not collected along the environmental gradients used as predictors.

Most natural resource spatial inventories are based on classified satellite imagery that describes distributions of vegetation communities across the landscape (Bain 1990, Bolstad and Lillesand 1992, Schowengerdt 1983). These communities are often described from in terms of dominant plant species (Verbyla 1995). Land management will typically assign a myriad of ecosystem attributes to each mapped community category to map other resource-oriented characteristics on the landscape (Bain 1990, Greer 1994). As a result, errors in the spectral classification are compounded with errors resulting from attribute assignment to yield maps that do not always portray a true spatial representation of ecological components (Foody and Curran 1994). Moreover, many ecosystem attributes are unrelated to the dominant species community type (see Foody and Curran 1994, Running and Coughlan 1998). For example, coarse woody debris loading can be the same for young forests as old forests, depending on disturbance history (Siitonen and others 2000). Mapping important ecosystem characteristics must use vegetation maps as predictor variables rather than as the final solution. For example, to accurately map fuel models, you would need to combine cover type and structural stage vegetation classification with environmental conditions such as temperature, moisture, and soils, in a predicative statistical model.

The primary satellite data to be used in this study is collected by the Enhanced Thematic Mapper Plus (ETM+) on the Landsat 7 satellite. With an acquisition history of 30 years, Landsat is a primary global data acquisition system at intermediate spatial resolutions. While maintaining compatibility with historical Landsat data, the ETM+ is geometrically and radiometrically superior to its predecessors (Teillet and others 2001, Vogelmann and others 2001a). ETM+ images are being used to develop a national land cover database for the entire US through the Multi-Resolution Land Characteristics (MRLC) 2000 effort; a multi-agency approach to addressing the data and land cover needs of those agencies. MRLC plans to acquire Landsat data for the entire nation every 5 years and update the national land cover database every 10 years. The vegetation classification data layers required for LANDFIRE, including cover type and structure stages, will be built upon the MRLC 2000 land cover database, and will be updated using new MRLC data sets with a 10-year or shorter interval. In order to develop the vegetation classifications we will link remote sensing with gradient modeling, allowing use to also map ecosystem process and characteristics.

Integration of Gradient Modeling and Remote Sensing

Some recent mapping and image classification efforts illustrate the power of formally melding environmental information with satellite imagery to develop better ecological maps. Michener and others (1992) combined GIS, field data, and spatial statistics to construct an effective tool for exploring oyster population dynamics. Ohmann (1996) demonstrated how regional plot data can be linked to gradients derived from climate models and digital maps to derive information relevant to forest planning and policy. For example, Ohmann and Spies (1998) used extensive field data to identify regional gradients for characterization of woody species composition in Oregon. This enabled them to develop a conceptual model of species environment relations at the regional scale. These models could be used to more accurately map forest species, from remote sensing. Ahern and others 1982 linked gradient analysis and spectral data to predict forest species distributions in the northern Cascades.

Keane and others (2002c) integrated gradient modeling with remote sensing to develop Landscape Ecosystem Inventory System (LEIS). LEIS is a system for creating maps of important landscape characteristics for natural resource planning, by linking gradient-based field inventories with gradient modeling, remote sensing, ecosystem simulation, and statistical analysis (Keane and others 2002c). The strengths of this approach includes: 1) a standardized, repeatable approach to sampling and database development for landscape assessment; 2) combining remote sensing, ecosystem simulation, and gradient modeling to create predictive landscape models; 3) flexibility in terms of potential maps generated from LEIS; and 4) the use of direct, resource, and functional gradient analysis for mapping landscape characteristics (Keane and others 2002c).

LANDFIRE will integrate gradient modeling with remote sensing (similar to the approach used by Keane and others (2002c) in developing LEIS) to create several key base layers needed to delineate fuel, fire, and ecosystem condition. We will collect, refine, or create a series of biophysically based GIS layers that describe the important environmental gradients that affect fire, fuel, and vegetation conditions. These biophysical layers will be derived from biogeochemical ecosystem models, 18 years of daily weather data, soils, and topography. We will use complex statistical procedures to generate the Biophysical Setting map (described in the METHODS section) and other ecosystem process maps (i.e., historical natural fire regimes) from the biophysical layers.

We will then incorporate the Biophysical Setting map into the remote sensing process to improve the mapping of cover types and structural stages. This improvement will include spatial accuracy (improved image classification) and cover type class discrimination (classifying additional number of cover type classes); and will be based on the principles behind gradient modeling. We will group the Biophysical Setting map up into a map of Potential Vegetation Types based on a series of statistical analysis.

The Potential Vegetation Types map will then be linked to Cover Types and Structural Stage maps to develop successional pathway models (see below); which we will use to simulate landscape changes (based on climate changes or management scenarios); and to describe ecosystem processes (i.e., historical natural fire regimes) and conditions (i.e., fire regimes condition classes and ecosystem status). We will also use the integration of these maps to delineate ecological attributes like fuel models and fuel loadings.

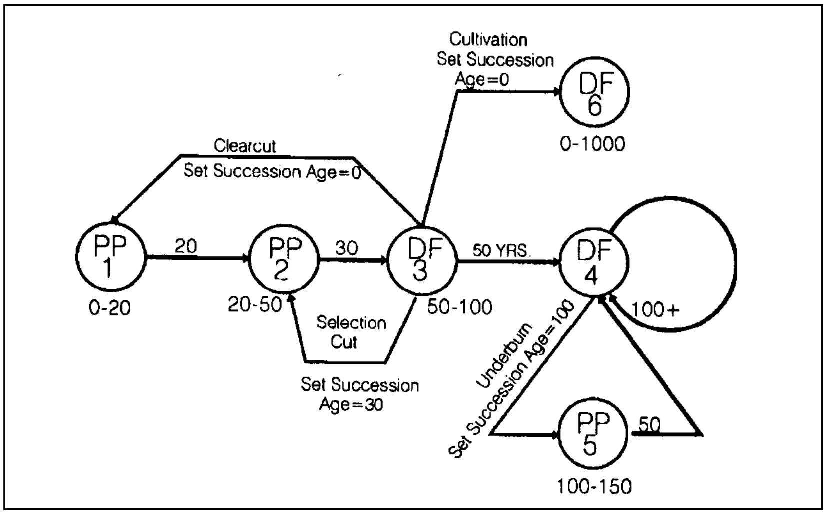
In addition, by integrating gradient modeling with remote sensing we will develop a hierarchical system that allows spatial data and predictive models to be scaleable at a national, regional, and local level. This integration also provides an efficient and affordable methodology for future re-measurements, because the relationship between ecosystem process and vegetative characteristics are static. This means that new remote sensed data could easily be plugged into the existing gradient models to produce several of the LANDFIRE maps.

Successional Pathways Models

Maps of Potential Vegetation Types, Cover Types, and Structural Stages created by integrating gradient modeling with remote sensing can directly be used in successional pathway modeling. We will use successional pathway modeling to create historical natural fire regimes and fire regimes condition classes maps. It will also be used to evaluate ecosystem status and fire hazard and potential status.

Succession pathways models incorporate plant succession with disturbances like fire, thinning, and grazing. It is the link between several vegetation communities along a network of multiple paths based on the development of biotic communities following disturbances (**Figure 1**). Vegetation communities are defined by combination of cover type and structural stages (based on stand attributes like stand age, canopy closure, and canopy layers).

Figure 1 – Hypothetical successional pathway model for a dry Douglas-fir stand. The number circles identify the vegetation communities.



The framework is based on a conceptual fire succession modeling approach developed by Kessell and Fischer (1981). They linked seral vegetation communities along multiple pathways of successional development (**Figure 1**). This approach assumes all pathways will eventually converge to a "stable" or "climax" plant community in the absence of disturbance. These climax plant communities are usually described in terms of Potential Vegetation Types. Potential Vegetation Types are a site classification based on vegetation and environmental factors. Disturbances disrupt successional development and can delay or advance the time spent in a vegetation community, or cause an abrupt change to another vegetation community. The length of time spent in a vegetation community depends on the shade-tolerance and life spans of the dominant species (Noble and Slatyer 1977). For more information on successional modeling, see (Keane and others 1996).

There are many advantages to incorporating successional pathway modeling into LANDFIRE. First, successional pathway modeling can be used to estimate historical condition dynamics. This is useful in creating historical natural fire regimes (Keane and others 2003), estimating the historical percent of fire regime condition class, and estimating historical range of variability of many ecological characteristics (Hessburg and others 1999). Comparisons between historical conditions and current conditions are extremely useful for evaluating ecosystem status. Second, successional pathway modeling allows use the ability to model changes in vegetation into the future using different management scenarios. These scenarios could then be compared, to evaluate differences between the management scenarios and if they meet a defined desired condition. Third, they allow use the ability to explore and understand these ecological systems. And fourth, when linked to spatial simulation models, like LANDSUM, they allows the ability to map these historical and future simulations. The greatest value of simulation modeling, like successional pathway modeling, is comparisons between historical, current, and future conditions. They are not meant to represent absolute changes on the landscape.

Ecological Attribute Mapping (Vegetative Triplet)

The same maps used in successional pathway modeling, Potential Vegetation Types, Cover Types, and Structural Stages, are used in mapping ecological attributes. Mapping ecological attributes is based on successional classifications principles; where for a given site, vegetative conditions change as plant communities move through time from early seral to climax (Steele 1984). These vegetative conditions can be described as ecological attributes like fuel models, fuel loadings, and snag densities.

The site is usually described in terms of potential vegetation types or habitat types classifications that delineate environmental factors like temperature, moisture, and soils (Pfister and others 1977) and are usually described in terms of potential or "projected" climax vegetation (Arno and others 1985). Climax vegetation is defined as a self-regenerating species that would occur on the site in the absence of disturbances like fire, grazing, and cutting (Daubenmire and Daubenmire 1968). Plant communities are usually described in terms of cover types and structural stages. Cover Types are based on the vegetation currently on the ground. They are generally delineated by the species with the most dominant overstory cover in the canopy. Structural Stages (SS) are stages of development of a vegetative community usually delineated by vegetative characteristics like age, height, and canopy closure.

Arno and others (1985) used this principle to summarize ecological attributes like tree canopy coverage, basal area, and stand age, to combinations of the following vegetation classifications: habitat types (site classification), dominant overstory species, and stand development (i.e., seedling, sapling, etc.). Steele and Geier-Hayes (1987, 1989, and 1993) summarized management implications (i.e., potential for pocket gopher damage, big game foraging preferences) to similar combinations of vegetation classifications. Using successional classifications principles, Quigley and others (1996) combined maps of Potential Vegetation Types, Cover Types, and Structural Stages, to map a suite of ecological attributes for the Interior Columbia Basin Ecosystem Management Project at the coarse scale. While Keane and others (1998a, 2000) used same types of maps developed at a fine scale to map FARSITE data layers for the Selway Bitterroot Wilderness Complex in Montana and Idaho and the Gila Wilderness Complex in New Mexico. This combination of Potential Vegetation Types, Cover Types, and Structural Stages maps are referred to as the vegetative triplet (Menakis and others 2000).

We will use the vegetative triplets to map fuel models, fuel loadings, and other data layers required for the FARSITE model. This will be accomplished by simply combining the vegetative triplet (in the GIS) to create unique combination of categories that can be used to compare with the reference plot field database. This comparison will be based on both statistical analysis and expert panels, and will be used to assign ecological attributes to the vegetative triplet combinations and then map the ecological attributes using the GIS. We could also use this methodology to map ecological attributes from other disciplines like wildlife, fisheries, and vegetation management. In addition, the layers used in successional pathway modeling are the same layers used in developing the vegetative triplets. This allows us to evaluate ecological attributes over time.

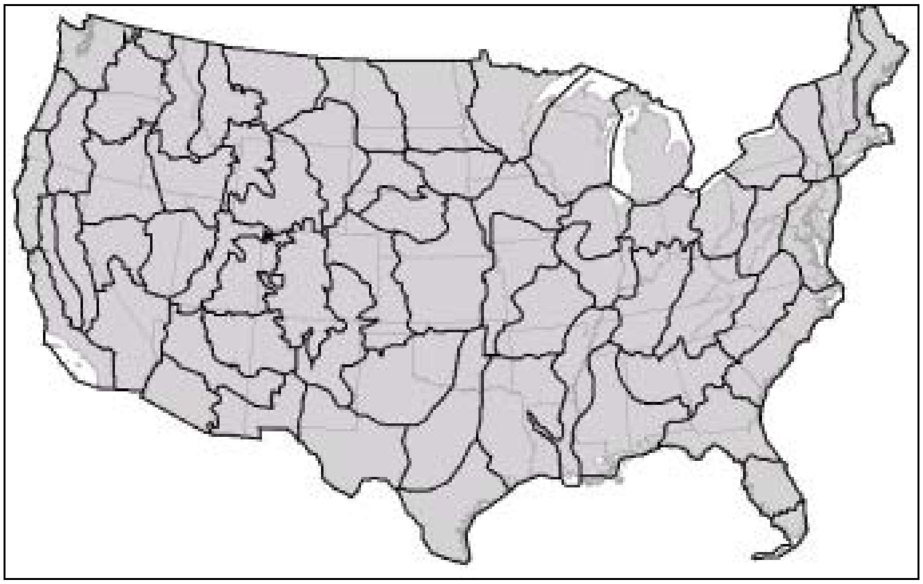
PROTOTYPE AREAS

LANDFIRE is designed to map and model vegetation, fire, and fuel characteristics for the conterminous US, and maybe Alaska and Hawaii in efficient and affordable manner. To complete this task, we selected two prototype areas to research, develop, evaluate, and test the best methods to map the rest of the country. The prototypes area were selected based on the following considerations:

1) Ecological diversity (a mixture of forest and non-forest communities)
2) Availability of satellite imagery
3) Extensive collection of existing field data
4) Previous research and experience
5) Current research project
6) Availability of extensive network of experts

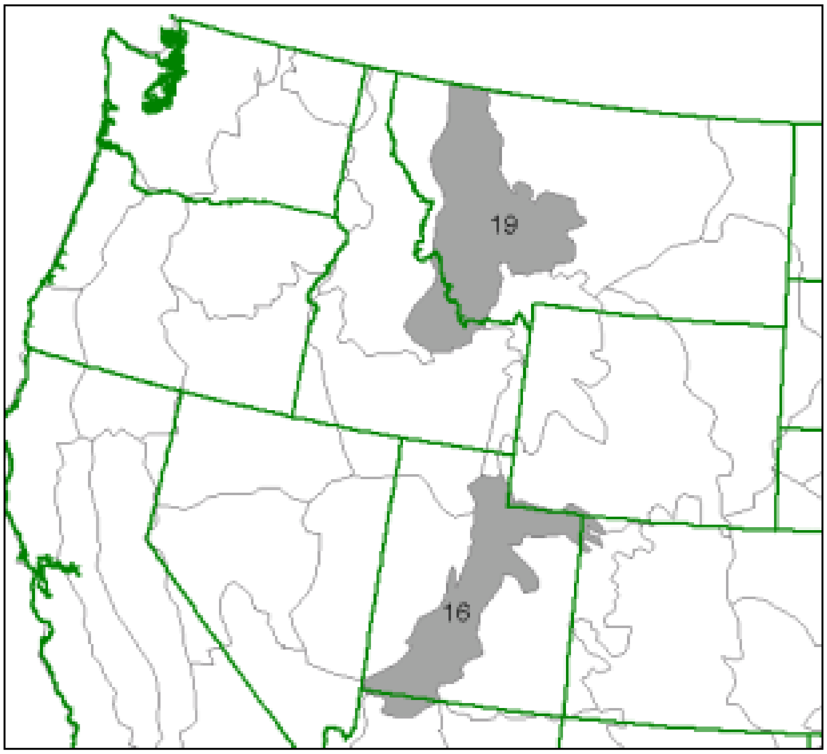
The prototype areas were selected from mapping zones used by USGS Multi-Resolution Land Characteristics (MRLC) 2000 mapping project (Figure 2). These mapping zones are original based on Omernick's ecoregions, but were modified to distinguish different vegetative communities from satellite imagery (Homer and others 2002). We selected mapping zones 16 and 19 for the prototype (Figure 3).

Figure 2 – MRLC Mapping Zones



Mapping zone 16 is located through the central Rockies of Utah, with over seven million hectares composed of 55 percent forests and 45 percent non-forested land. This is the primary prototype area used to develop and demonstrate all maps, models, and other products. Mapping Zone 19 is located in the central Rockies of Montana and north central Idaho, with over ten and half million hectares composed approximately of 65 percent forested lands and 35 percent non-forested lands. This secondary prototype area is used to test the methods and conduct additional research and development of the products, but for uniquely different area.

Figure 3 – LANDFIRE prototype areas.



METHODS

The LANDFIRE products can be broken into three main groups: 1) maps that characterize vegetation and fire regimes, 2) maps that characterize fuel conditions, and 3) maps and models used to evaluate ecosystem status and fire hazard and potential status. The creation of these products will be accomplished by integrating complex GIS spatial analysis, innovative image processing procedures, ecosystem simulation modeling, and multivariate statistical, regression tree, and neural networks techniques with various maps, field plot data, and simulations of spatial and tabular data products.

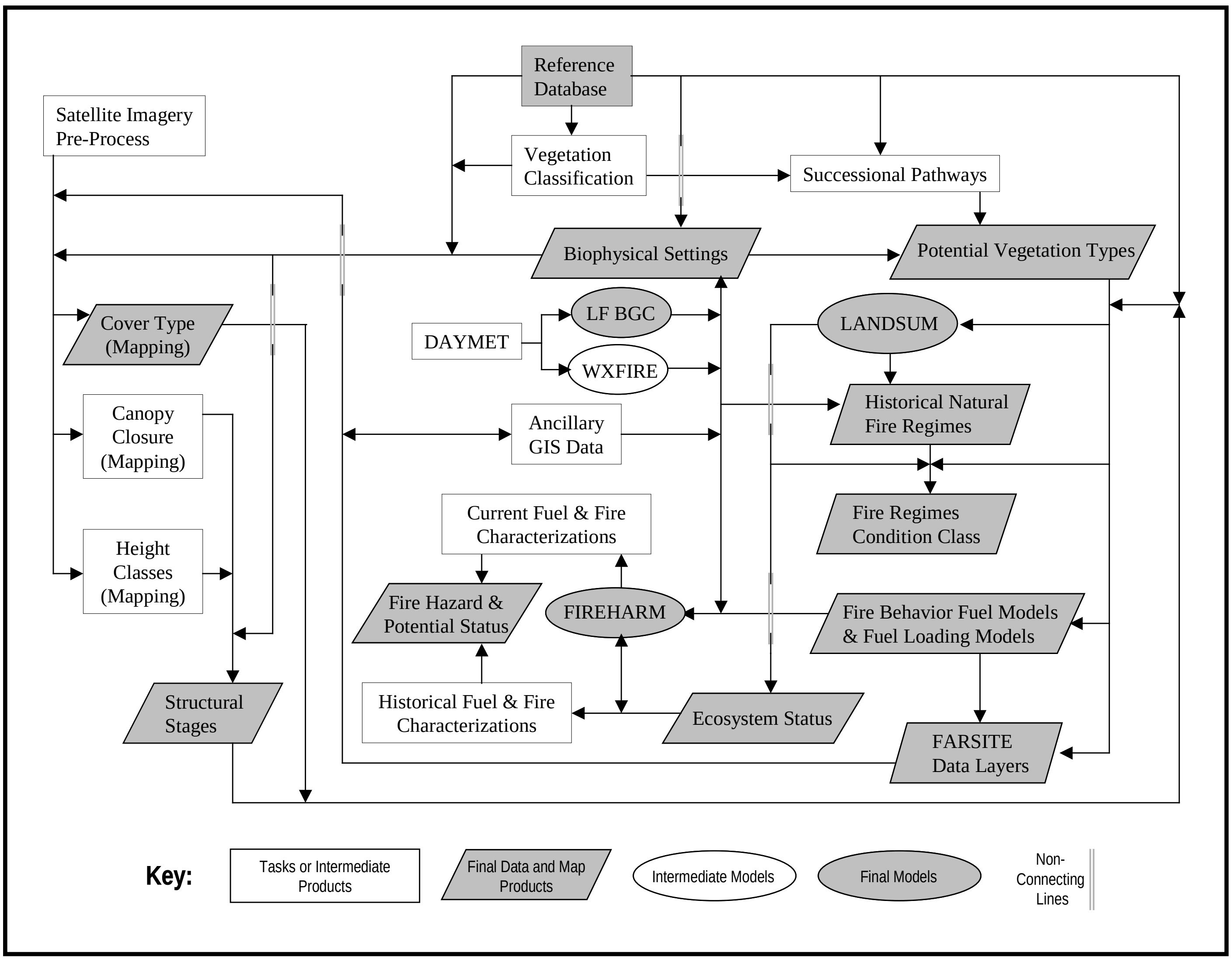
This extensive project will use an approach somewhat similar to that used by Hardy and others (2001) to create the coarse scale fire regime condition class maps, except classifications of vegetation, historical natural fire regime, and succession pathways will be (1) more detailed, (2) based on fundamental ecosystem processes with scientific foundations, and (3) tailored to local situations. Increased detail in the classifications will be designed to be hierarchical so that information can be simplified and aggregated as area of assessment (e.g., region-to-nation) becomes larger. We will also create a process where higher resolution data can be added by local personnel to improve fuel condition and ecosystem status mapping for their land areas. This project differs substantially from Hardy and others (2001) in that the base maps used to drive the process need to be created from scratch.

This project will have specific scale requirements for map development (some of these requirements were described in the LANDFIRE OVERVIEW section above). First, all maps will be raster maps composed of 30-meter pixels, which represents a fine-scale mapping strategy. However, biophysical and vegetation classifications will be created for mid-scale applications (1:50,000 to 1:100,000 mapscale or National Forest level). Biophysical classifications, like potential vegetation types and biophysical settings, will be based on groups of homogeneous 30-meter pixels (i.e., polygons). Vegetation classifications keys will be created at the mid-scale, but mapped for each 30-meter pixel.

This apparent contradiction in mapping scales was created for many reasons. First and most importantly, the fine-scale mapping of vegetation allows local management agencies to rename (or reclassify) the vegetation classifications keys to a finer-scale that might be better suited for local applications. This then allows the final map products to be stepped down to finer scales if a land management agency desires. Stepping down the data can be accomplished by using the methods and databases developed for the project as well as incorporating higher resolution data developed at the local level. The vegetation classifications key, however, cannot be divided into finer categories because of the national scope of this project. It would be impossible to comprehensively and consistently classify all cover types at classification scales needed by land management, as witnessed by the nationwide FDGC vegetation classification project. Also, the project would never be able to collect enough plot data to image classify all these cover types. LANDFIRE classifications must be designed for application nationwide so that a cover type in Montana, ponderosa pine for example, means the same as a ponderosa pine cover type in New Mexico. So, a fine scale spatial resolution was retained in LANDFIRE to allow the step-down to finer scales if desired by any land management agencies, but the vegetation classification keys were kept at a mid-scale to remain consistent across the spatial domain of LANDFIRE (i.e., the continuous US). LANDFIRE will develop lookup tables to existing finer scale vegetation classifications.

The procedures used to accomplish the project objectives are so complex, that it is best presented by the steps needed to create each of the products. Since several of procedural steps are common to most products, these tasks will be discussed in the order they occur. Figure 4 provides a general flow diagram of the major tasks, computer models (or programs), and the final products. The SCHEDULE section provides a timeline for each of the tasks (described below) by each of the mapping zones described in the PROTOTYPE AREAS section. As stated earlier, we will use the appendices to provide detail descriptions, methods, and eventually results. The appendices will not be available in this document, but will be available and updated through out the life of the project, with the current updates available on the web (www.landfire.gov).

Figure 4 – General flow diagram of major LANDFIRE task and products



The METHOD section has been broken down into eight sub-sections (in bold). The **Core Data** section describes the development of the Reference Database and the collection and pre-processing of critical ancillary GIS layers. The Reference Database, probability one of the most critical components of the project, is a collection of all the field plot data available for the map zones. We will use the Reference Database to develop all classifications, maps, and models. The ancillary GIS layers will be based on existing GIS layers, which will be processed to create additional critical GIS layers, such as DEMs being processed to create slope and aspect. These ancillary GIS layers will be used in many phases of the project.

In the **Environmental Classification** section, we describe the methods used to create the Biophysical Setting and Potential Vegetation maps. The development of these maps is based on gradient modeling (describe in the BACKGROUND section) and will be developed by using complex statistical analysis procedures on maps of biogeochemical processes, weather, and ancillary GIS layers. The **Vegetation Classification** and **Image Classification** sections will be used to describe how we will develop the vegetation classifications to create maps of Cover Type and Structural Stages. To complete this task, we will link the Biophysical Setting map with satellite imagery, based on the science of integrating gradient modeling with remote sensing.

In the **Successional Modeling** section, we will describe the methods used to develop Successional Pathway Models, from the Reference Database and vegetation classifications. We will then link the Successional Pathway Models to the LANDSUM model and maps of Potential Vegetation Types, Cover Types, and Structural Stages to spatial model past and future vegetative conditions. These models will be used to create Historical Natural Fire Regimes and Fire Regimes Condition Class maps describe in the **Fuel and Fire Characterization** section. They will also be used to evaluate Ecosystem Status and Fire Hazard and Potential Status described in the **Landscape and Assessment Modeling** section.

In the **Fuel and Fire Characterization** section, we will also describe the development of Fuel Models, Fuel Loading, and FARSITE data layer maps. These maps will be developed, using successional classification principles to map ecological attributes (described in the BACKGROUND section). We create these maps by assigning ecological attributes (i.e., fuel models) to unique combinations of Potential Vegetation Types, Cover Types, and Structural Stages maps based on detail statistical analysis of the Reference Database. We will also describe the methods used to develop other maps that characterize fuel condition based on fire behavior, fire effects, and fire danger indices. These maps will come from the FIREHARM program, which uses maps of Biophysical Settings, Fuel Models, and Fuel Loadings along with weather data.

In the last section, **Management Tools**, we will describe the methods and tools required for land managers to use and understand the data. This section will describe the development of an interactive web page and management tools to both summarize the data at any scale and to step the data down to a fine scale. We will also discuss how we plan to provide for technical transferring the data and the methods to land managers.

CORE DATA

Arguably, the most critical resources element of any mapping and modeling project is the field data used to create, test, and validate the generated maps and model runs. Geo-referenced field data are important for many reasons. First, field data provide important **ground-reference** or an accurate description of what is being remotely sensed, statistically mapped, or modeled. In LANDFIRE remote sensing, the field data will be used to map cover type, canopy closure, and height. This means sampled points or polygons can be used as **training areas** in satellite imagery classifications using various classifiers (Jensen 1998, Verbyla 1995). In statistical mapping, the field data will be used to map biophysical classification and potential vegetation types from several GIS layers. In modeling, the field data will be used to develop, evaluate, and summaries models.

Second, field data are important in defining classification keys and ecological attributes. The field database will be used to refine the cover type classification key by summarizing the distribution and frequencies of occurrence for each cover type classes across the landscape. The potential vegetation classification will also be based on the field database and the relationship between vegetation occurrence and biophysical settings (Keane and others 1998b). The field data will also be used to develop a comprehensive relational database between potential vegetation type, cover type, and structural stages to many ecological attributes like fuel loadings, fuel models, and crown bulk density (Menakis and others 2000). This relationship is also critical in creating successional pathway models, which are needed to create maps of historical natural fire regimes and fire regimes condition classes(Keane and others 2003).

Lastly, field data provides a means for quantifying accuracy and precision of developed maps and key classifications. This will provide important validation information to the user. In addition, field data provides a means for interpreting maps and classifications, and for exploring the reasons for inaccuracies or inconsistencies in the maps and classifications.

In addition to collecting plot data, we will also acquire all existing GIS layers required to complete the project. These GIS layers would be used as inputs into existing models or mapping methodologies required to create additional GIS layers need for the project. For example, maps of soil composition are required inputs into the biogeochemical process model, which is used to create maps of ecosystem processes that are inputs into the biophysical settings map. The soil composition maps will come from the STATSGO layers. Only GIS layers that occur in the conterminous US will be collected for this project, since all methods have to be developed and based on the ability to create LANDFIRE products at a national level.

We have broken the core data into two separate tasks. The first task is **Creating the Reference Database**, which is used to compile and process all the field plot data collected for the project. We will aggressively pursue and collect all existing field plot data available for the two mapping zones, which will be used to develop and test all classifications, maps, and models. The second task is **Acquiring and Pre-Processing Ancillary GIS Layers**, which is used to describe the collection and pre-processing of all existing ancillary GIS layers required for the project.

Creating the Reference Database

The LANDFIRE Reference Database is a comprehensive collection of all existing geo-reference plot data available and appropriate for the prototype mapping zones and will be used in most phases of the project. The Reference Database is composed of a series of smaller different databases that group different types of data (i.e., tree measurements, fuel sampling, and fire history) into one architecture. The database will be designed in Microsoft ACCESS database software and consist of a four level database structure (**Error! Reference source not found.**). Level IV, the lowest level, will consist of existing geo-reference data in their Raw Format. This is the original format and structure the data was stored in by the original owners, when the LANDFIRE personnel acquired the data. Level III is a conversion from the Raw Format to the Fire Effects Monitoring System (FIREMON) standardized database structure (Keane and others 2002a). Level II is a summary of the FIREMON data structure to the LANDFIRE Attribute Database. And Level I is a summary of the LANDFIRE Attribute Database to a LANDFIRE Map Database that will be used in remote sensing and statistical mapping.

Table 1 -- The Reference Database structure developed for LANDFIRE.

Level	**Database Label**
Level I	LANDFIRE Map Database
Level II	LANDFIRE Attribute Database
Level III	FIREMON Database
Level IV	Raw Format (native structure and format the data was collected in) and Conversion Programs (to load it into ACCESS)

Level IV field data will be collected by LANDFIRE personnel from many government, universities, and private organizations in the prototype areas. Potential federal sources would include, but not limited to are:

USDA FS: 1) Forest Inventory and Analysis (FIA),
2) Forest Health Monitoring (FHM),
3) Landscape Ecosystem Inventory Systems (LEIS) (Keane and others 2002c),
4) ECODATA (Hann and others 1988), and
5) Interior Columbia River Ecosystem Management Project(Quigley and others 1996); and

US DOI: 1) National Range Inventory (NRI),
2) Natural Resources Conservation Service (NRCS), and
3) National Park Service Fire Monitoring plots.

The minimum requirement for a plot to be included into the LANDFIRE Reference database is as follows.

1) All plot data must have a reasonably accurate geo-references location.
2) The data must quantify or relate to at least one LANDFIRE mapping attribute (i.e., cover type) or process attribute (i.e, soil depth).

All field data will be evaluated for suitability to the project and then prioritized for conversation into the Reference Database based on the type and amount of information. Existing geo-spatial databases and maps will also be evaluated and summarized, but at a lower priority to plot data. The ESRI ArcInfo GIS program will be used to summarize geo-spatial data into a Reference Database format.

Once the data has been acquired and loaded into the Level IV data structure. A series of conversion programs will be created and run to convert the data to the Level III data structure – FIREMON. FIREMON will be the lowest consistent level of the Reference Database (all data in the same format with the same field names). FIREMON integrates new and current ecological field sampling methods with remote sensing of satellite imagery to assess the effects of fire on important ecosystem components (Keane and others 2002a). FIREMON has several standardized sampling procedures and databases that would blend well with LANDFIRE, like Species Composition, Tree Data, and Dead Fuel. Moreover, additional FIREMON databases can be created for LANDFIRE.

Level II and Level I of the Reference Database will be used to develop, test, and map many of the LANDFIRE products. The LANDFIRE Attribute database (Level II) will be used to evaluate and summarize model parameters and map-able ecological attributes based on several spatial layers. Examples of Level II data would be: unique register for the plot, sampling date, examiners name, size of plot, type of plot, etc. Level I will be used to develop, test, and evaluate all remotely sensed and statistical maps. Most reference data provided to EDC by the LANDFIRE team will be Level I. Examples of Level I data would be: unique plot register, cover type, dominant species, tree height, shrub height, grass height, etc.

The Reference Database is one of the LANDFIRE products and will be made available on WEB through interactive windows. Because certain field data used by LANDFIRE are proprietary (e.g., FIA), certain security measure will be put in place to protect this data. Proprietary data will only be used by LANDFIRE personnel, and will be stored in a secure database that is identical to the Reference Database. The secure database will not be apart of the LANDFIRE products.

A complete description of the methods and structure of the Reference Database can be found in Appendix A.

Acquiring and Processing Ancillary GIS Layers

The primary core data that describe vegetation, fuels, and fire characteristics for mapping and modeling, will come in forms of field point data (plots) contained in the Reference Database (see previous discussion). In addition, we will acquire **existing** spatial ancillary data needed for: inputs into developing maps or models; and referencing and summarizing maps of the final products. These spatial ancillary data will be listed and described below. Only those spatial data (GIS layers) that have a critical application for LANDFIRE tasks will be included. Several of these GIS layers will be processed to create additional GIS layers required for the project. For example, we will derive slope and aspect from elevation. Where appropriate, all ancillary GIS layers will be resampled to a spatial resolution of a 30-meter pixel size. We will only collect GIS layers that have been developed for the conterminous US, since all methods for this project have to be developed and based on the ability to create LANDFIRE products at a national level. In addition, these layers must be documented and if possible published with copious metadata and significant support.

GIS layers required for inputs into maps and models included: topography, soil, hydrology, tree ranges, and biogeochemical ecosystem maps.

Topography – will come from USGS 1-arc second National Elevation Dataset. We will use this 30-meter pixel size Digital Elevation Model (DEM) to derive slope and aspect. These topographic layers are key inputs into developing the Biophysical Setting map, image processing the vegetation classification, and the fire-spread model FARSITE.

Soils – will come from State Soil Geographic (STATSGO) Data Base (NRCS 1994). We will use STATSGO to create layers of water capacity, soil carbon content, and soil quality index, which will be inputs into developing the Biophysical Setting maps and image processing of vegetation classification. We will also extract soil depth, and soil composition (percent sand, silt, and clay) to be used as inputs into the biogeochemical process model (LF-BGC), which will be used to create several layers of ecosystem processes needed to derive the Biophysical Setting map.

Hydrology – will come from 4th code and 6th code (if available for the nation) Hydrologic Unit Codes (HUCs) (Seaber and others 1987). These watershed boundaries are polygon based, which we will use to develop and test the appropriate polygon size needed to map biophysical setting, potential vegetation types and fire regime condition class. These watershed boundaries will also be important to federal land managers for summarizing the final products.

Tree Ranges – a 1-kilometer resolution datasets available on the web for identifying where tree species are known to exist. This data layer will be used as input into the biophysical setting map.

Biogeochemical Ecosystem Maps – will come from a national effort by NOAA, to map biogeochemical process at 1-kilometer resolution by fall of 2002. We will use these data layers as input into mapping biophysical settings.

We will also acquire additional GIS layers that delineate geo-political and reference features needed by managers for making maps and spatial summaries. These maps will be acquired at the best scale and quality available. The target mapscale for these layers would be 1:100,000.

State –a layer that delineates state boundaries for the conterminous United States.

Counties – a layer that delineates county boundaries for the conterminous United States.

Ownership – a layer that delineates federal ownership for the conterminous United States. (*It is important to note that we will only use the best coverage available, and will not develop a new federal ownership layer*.)

Cities – a layer that delineates cities for the conterminous United States.

Roads – a layer that delineates roads for the conterminous United States.

Rivers – a layer that delineates rivers for the conterminous United States.

A complete description of the source, methods and processing of the Ancillary GIS layers can be found in Appendix B.

ENVIRONMENT CLASSIFICATION

Environmental conditions can best described as the compilation of ecological process that drive where, when, and, how vegetation grows. Environmental conditions represent long-term ecological influences on the landscape and they have been traditionally described by parameters such as weather or climate, soils and topographical information (elevation, slope, and aspect) (Hardy and others 1998). Mapping environmental conditions are important for many reasons. First, environmental conditions limit the number of floral species or plant community types which are expected to occur on a site (Hardy and others 1998). Second, Keane and others (2000) found mapping accuracies increased by 20 to 30 percent when environmental conditions are included in mapping cover type and structural stages. Third, environmental conditions variables were found to be statically significant in mapping fire regimes and fuels (Keane and others 2003, Rollins and others 2003). Lastly, mapping biophysical variables allows for landscape comparisons to global climate change scenarios. Environmental conditions have been traditional classified into maps of biophysical setting and potential vegetation types.

Biophysical setting maps have been developed and used in a few different mapping projects. The Interior Columbia Basin Ecosystem Management Project created biophysical settings of temperature/moisture classes for three physiognomic types (forest, shrubs, and herbaceous) based on combinations of elevation, aspect, and slope classes within each Bailey's Subsection (Reid and others 1995). They then used the biophysical setting layers to create a potential vegetation type of layer based on aggregation of the biophysical setting classes and image-classified maps of lifeforms. Kuchler's Potential Natural Vegetation map (Kuchler 1964, 1975) has been used in mapping Historical Natural Fire Regimes for the western US (Hardy and others 1998) and conterminous US (Schmidt and others 2002). Milner and others (1996) used FOREST-BGC coupled with a climate model to create a biophysical soil-site model for predicting timber productivity in Montana. Biophysical environmental variables were used by Keane and others (2003) in mapping fire regimes and fuels for two watersheds in Idaho and Montana.

LANDFIRE will create the **Biophysical Settings** layer by synthesizing all biogeochemical, climate, soils, and topography input data into a set of variables related to environmental conditions. These variables will come from biogeochemical (**LF-BGC**) and climate (**WXFIRE**) models; spatial weather data (**DAYMET**), soils data (STATSGO), and topographic data (DEM); and image processing. We will describe in more detail, **DAYMET WXFIRE**, and **LF-BGC** below. The Biophysical Setting will not be mapped at a 30-meter pixels size because:

1) space and computing resources are limited,
2) output generated by **LF-BGC** is more appropriate to the larger spatial scale,
3) the input weather information is at a coarser scale (1-square kilometer pixel size), and
4) it would be difficult to delineate biophysical settings below a stand level even with finer data.

Instead, we will explore different mapping polygons sizes and/or pixel cell sizes (from 100 square meters to 1-kilometer) to map biophysical setting. These polygon layers could be delineated using remote sensing image segmentation, 6th code HUCs, topography, and/or combinations of all three. The **Biophysical Setting** layer will be used to create the **Potential Vegetation Type** layer, which we will describe the methods below.

Creating and Summarizing Weather and Climate Data

Weather data is used in LANDFIRE to simulate or estimate those environmental conditions that influence vegetation and fuel dynamics. Daily weather for the entire US was simulated from DAYMET. WXFIRE is used to summarize the DAYMET weather data into many different climate maps.

DAYMET is a collection of algorithms and computer software designed to interpolate and extrapolate from daily meteorological observations to produce a gridded estimate of daily weather parameters over large regions (Thornton and others 1997). DAYMET takes daily weather collected at monitored weather base stations and extrapolates five weather variables across the landscape (1 km pixels) using biophysically based statistical techniques (Thornton 1998). Thornton (1998) compiled extensive weather station data from various sources including NOAA, National Weather Service, and USGS Natural Resource Conservation Service SNOWTEL data into one database suitable for input to DAYMET. The DAYMET database contains daily weather from 1980 through 1997 for each 1-km^2 pixel in the conterminous US. The database is composed of five weather variables: (1) minimum temperature (degrees C), (2) maximum temperature (degrees C), (3) relative humidity (%), (4) precipitation (cm), and (5) radiation (kW m^{-2}). Although the DAYMET database is not temporally deep (only 18 years), the database is spatially comprehensive and consistent, thereby making it highly desirable for this project. This database will be used as inputs to create the biogeochemical layers needed as input for the creation of the biophysical settings, historical natural fire regimes, ecological status, and fire hazard and potential layers.

WXFIRE is a model used to summarize DAYMET data into integrated measures of local weather/climate for a geographic area. WXFIRE uses the five DAYMET weather variables to summarize weather related variables such as average annual precipitation, average maximum summer temperature and average annual solar radiation; and to simulate important weather related variables such as potential evapotranspiration, soil water potential, and vapor pressure deficit. The model can also compute daily fire danger indices such as Energy Release Component, Burning Index, and Keetch Byron Drought Index. These weather summaries will be used in the creation of the biophysical settings, historical natural fire regimes, ecological status, and fire hazard and potential layers.

Creating the Biogeochemical Model Data Layers

LF-BGC is a biogeochemical (BGC) ecosystem model being developed specifically for LANDFIRE, from the ecosystem simulator BIOME-BGC developed by Running and Hunt (1993) and Thornton (1998). BIOME-BGC simulates fluxes of various carbon, nitrogen, and water pools at the stand and landscape level using mechanistic eco-physiological process relationships. It is a “Big Leaf” model where stand conditions are represented by the various carbon pools (Running and Coughlan 1988).

LF-BGC (LANDFIRE- BioGeoChemical model) is being designed with a user-friendly interface to run on the PC and link to the Reference Database in ACCESS. Unfortunately, this does not necessarily mean the model will be easy to use. Developing the parameterization files (input variables) and the initialization files (starting point at the landscape level) to the model will take time. First, inputs describing eco-physiological parameters (e.g., stomata conductance) have to be populated for every LANDFIRE cover type. This information will come from a combination of sources including: field data, literature review, model test runs, and expert opinion. Second, inputs of standardized site parameters (e.g., percent sand, silt, and clay) and weather parameters (coming from DAYMET) need to be calculated from GIS layers. Lastly, it will take multiple model runs to sensitize the model to produce outputs within acceptable limits based on the literature.

LF-BGC will be designed with standard outputs (Table 2) to best depict the eco-physiological processes that drive key LANDFIRE products, like biophysical settings, potential vegetation types, and historical natural fire regimes. The model is also being designed to run on specific geographic points that have been delineated by the center of polygons or plots, instead of all pixels in a polygon. The rational behind this is the program is computationally intense. Test runs on a creating 1-square kilometer pixel maps for mapping zone 16 took about 15 seconds per pixel; based on these numbers it would take about four and half months to map the whole map zone. This would make mapping the conterminous US difficult to impossible because of the time and processing constraints.

Table 2 – LF-BGC will produce the following products for each parameterized cover type.

LF-BGC Output Variables	Units
Net Primary Productivity – Average Annual	
Net Primary Productivity – Variability	
Evapotranspiration – Average Annual	
Evapotranspiration – Variability	
Nitrogen Limitation Index	
Leaf Area Index	
Soil Carbon	
Litter Carbon	
Total Vegetation Carbon	
Water Use Efficiency	
Recovery after disturbance (the number of years it takes carbon to return to neutral after a disturbance)	

Creating the Biophysical Settings Layer

Biophysical settings are areas of similar site conditions represented by the environmental gradients that influence vegetation, fire and fuel dynamics. Biophysical settings must scale across time and space and they must be fully integrated with potential vegetation type classifications. A spatial delineation of biophysical settings across a landscape, regardless of scale, is critical for the development of nearly all LANDFIRE products including fire regimes, succession pathways, and fuel mapping. However, the mapping of biophysical settings is inherently complex and problematic for many reasons. First, the delineation of biophysical settings must be comprehensive and consistent across the entire United States; a biophysical setting category in southern Utah must match the same biophysical setting category in northern Montana. The biophysical settings must be designed to link to potential vegetation type classifications so that succession can be modeled and mapped. The environmental gradients that control vegetation and fuels are quite complex and some are not known or immeasurable using field sampling, and it difficult to evaluate the importance of one environmental gradient over another because the importance changes over time and space.

We will map biophysical settings using all available spatial data that describe important gradients that affect vegetation and fuels across the US. Some data layers will be developed at the Fire Sciences Laboratory specifically for the LANDFIRE project. These include solar isolation, soils depth and texture, and landform position. Others will be taken from other studies or projects, such as nitrogen availability (ORNL), NPP (MODIS), and greenness (EDC). And last, others will be simulated from the computer programs LF-BGC and WXFIRE, such as NPP, ET, and degree days. These data will be input to statistical programs to identify natural clusters or groupings based on these environmental gradients. These clusters will be named by the most important environmental gradient used to identify the cluster, and then they will be mapped at two, and maybe three, scales. Attributes such as potential vegetation type, succession pathway model, and lifeform will be assigned to each biophysical setting category based on an assessment of field data. The following is a detailed procedure for identifying and mapping the clusters that will define biophysical settings.

The following tasks detail a procedure for classifying and mapping biophysical settings at multiple scales for the LANDFIRE project. However, we will first discuss issues of resolution and scale before going into the methods.

Biophysical Setting Spatial Resolution. There is still considerable debate about what constitutes the most appropriate LANDFIRE analysis spatial resolution. Is it a 30 meter pixel, a polygon, a 250 meter pixel, or a 1 km pixel? This method is designed to be implemented at whatever spatial resolution the LANDFIRE research team decides. Next, we have designed all LANDFIRE spatial tasks to be analyzed, simulated, or summarize in a list or in an aspatial context. This list is created from the GIS and each item in the list is the smallest spatial mapping unit, such as a pixel or polygon. The list approach allows flexible processing by independent teams, but the spatial relationships such as adjacency, juxtaposition, and connectivity must be integrated in the list in awkward and inefficient means.

Biophysical Setting Analysis Scale. To ensure comprehensive and consistent mapping of biophysical settings across the entire United States, it was decided that there be two simultaneous efforts at mapping biophysical settings, but at separate scales. The first effort, called the **National Biophysical Settings Effort**, will be to identify broad scale biophysical settings at the scale of the entire United States. This effort will use the same input data that the second effort uses, but at a coarser resolution (1 km). The idea behind this national effort is that broad scale biophysical settings can be identified so that the same environmental conditions will yield the same biophysical settings, no matter where you are in the United States. This effort will identify 100-200 biophysical settings categories that may be associated with landform, lifeform, or ecosystem properties at the continental scale. This then sets the context for the mapping of biophysical settings at the finer LANDFIRE scale of 30-100 meter pixel sizes that is the second effort. This second effort, called the **Biophysical Setting Mapping Zone Effort**, will perform near identical analysis as the first effort but at the EDC mapping zone level (or smaller scales). The second effort will nest the subsequent mapping zone biophysical settings clusters within the coarse scale biophysical settings clusters identified in the primary effort. For example, there may be 15 national biophysical settings categories delineated in the central Utah mapping zone. A finer scale biophysical mapping effort shows that there are six biophysical settings within the second of the 15 coarse scale categories. These new biophysical settings classes might be named 2.1, 2.2, … 2.6, or PJ-southern Utah, PJ-central Utah, PJ-Moab, etc.

Obviously, the coarse scale mapping of biophysical settings at the continental scale will require more time than available for the prototype effort. Therefore, the mapping of the biophysical settings for the prototype area will be done independently of the coarse scale biophysical mapping effort. It is hoped that the final prototype biophysical settings map can be fully integrated into the coarse scale biophysical settings mapping effort once finished. This is possible because the mapping of biophysical settings in the first zone does not require a national mapping effort because they are not compared across other map zones.

Input Data for Mapping Biophysical Setting. The biophysical settings maps will be created from many GIS layers. These layers will come from a multiple of sources. We will use LF-BGC and WXFIRE to create a suite of maps that predict biophysically based environmental gradients across mapping zones. These models must be executed across all map units in a mapping zone for the 18 years of weather in the DAYMET database. This will be done for the two mapping zones in the LANDFIRE prototype. The National Biophysical Setting Effort will use the NOAA 1-kilometer resolution BGC maps described earlier in the Ancillary GIS Layers section. NOAA data layers will not be available until the fall of 2002. We will also run WXFIRE at a 1-kilometer resolution to augment the NOAA BGC maps.

We will also create input maps need to map biophysical settings from the following GIS layers described earlier in the Ancillary GIS Layers. These data layers are consistently mapped across the entire United States, making them applicable to both biophysical mapping efforts (national and prototype map zones). We will use topography from the National Elevation Dataset, soils information from the STATSGO Data Base, and Tree Ranges.

Creation of Biophysical Settings Database. Attributes of each mapped units of the input data for mapping biophysical setting (described above) will be outputted to a list. Each line in this list is the mapped unit (pixels or polygons) and each line contains a list of numbers that correspond to the values of various layers for that mapped unit. For example, the first line in the list is for pixel number one and on that line are the variables such as latitude, longitude, solar insolation, NPP, ET, and so on. This list can be for an entire MRLC mapping zone, or for any part of the mapping zone.

Biophysical Settings Cluster Analysis. The biophysical settings database will be input to a statistical package such as SAS, SPLUS or CART to identify the major biophysical clusters using the environmental gradients. This procedure is quite fluid and here are some lines of investigation to ensure success. First, the hundreds of environmental gradients might be summarized into 3-5 factors using Principle Components Analysis or Factor Analysis. However, it may be perfectly plausible to use the raw gradients in the cluster analysis. Next, it may be necessary to remove a fraction of the lines in the list to streamline or allow efficient computing; it is highly doubtful that we need the millions of pixels in the analysis to identify clusters. It may be that the software and hardware will not allow the extensive analysis of so many variables from so many observations. Appropriate clustering techniques and statistical methods will need to be explored. Robust clustering techniques such as K-means might not be possible because of data limitations. A combination of several techniques may be possible.

The end product of this clustering analysis is when each line in the biophysical settings database will be assigned a number that identifies a biophysical settings category for that piece of land. This allows the mapping and modeling of mapping units in space.

Biophysical Settings Cluster Naming. Each biophysical settings cluster on the landscape will receive a number and a name. The number is a code for the biophysical settings that allows the hierarchical nesting of biophysical settings across scales. For example, the national biophysical settings cluster ID will be the first number in this sequence and the fine scale cluster assignments will be the second number. The hardest part of this system is to name the clusters a meaningful and intuitive label that can easily be interpreted for any part of the country. We plan to construct the label from a combination of three factors. First, we would like to name the biophysical settings on some sort of geographic location system. Then, a lifeform or vegetation based description would be in order. And last, the most important gradients used to define the cluster should be integrated in the name. An example might be Pacific Northwest Cold, Dry Conifer Forest at the national scale and NW Oregon upper subalpine conifer forest for a finer scale settings name. Goals for the naming system will be 1) hierarchical, 2) scaleable, and 3) consistent. At the end of the cluster naming process, we will have developed the **Biophysical Setting** layer.

Biophysical Settings Attributes. Many ecosystem attributes and characteristics will be assigned to each biophysical setting category. We will use Reference Database to assign attributes to each biophysical settings category. For example, to image classify vegetation classifications, we needs a list of possible cover types that can exist on each biophysical setting. So, we will query each plot that is wholly contained within a biophysical setting to create a list of important species used in the satellite mapping effort.

A complete description of the methods and process for creating Biophysical Setting layers, using DAYMET, and running WXFIRE and LF-BGC can be found in Appendix C.

Creating the Potential Vegetation Types (PVT) Layer

Many authors have mapped PVT at different scales. Kuchler (1964) and Schmidt (and others 2002) mapped PVT at a course scale for the conterminous United States. Keane and others (1998a, 2000) mapped PVT at the mid to fine scale for the Selway Bitterroot Wilderness Complex in Idaho –Montana and the Gila Wilderness Complex in New Mexico. The mapping PVT is important for this project for the following reasons. PVT is needed to develop the Successional Pathways Models and run LANDSUM across the landscape. And, PVT is key in assigning and mapping many ecological attributes using the vegetative triplet (Menakis and others 2000).

LANDFIRE will create PVT map from the Biophysical Setting layer and the Reference Database. We will use a combination of multivariate statistical techniques coupled with regression tree analysis and neural networks to develop an algorithm that assigns the most likely PVT to a biophysical setting. The Reference Database will aid in the completion of this task because PVT will be one of the data fields specified or calculated from the plots. The PVT classification (key) will be based on the vegetation classification and successional pathway model described below in the sections below.

A complete description of the methods and process for creating Potential Vegetation Types map can be found in Appendix D.

VEGETATION CLASSIFICATION

Critical to LANDFIRE, is the need to develop a vegetation classification (or key) that links the vegetation spatial data layers together into a systematic, hierarchal, easy-to-scale format. This hierarchal vegetation classification will be used to develop individual classifications (mapping keys or legends) for Potential Vegetation Types, Cover Types, and Structural Stages. These classifications are critical to the following tasks.

1) Remote sensing vegetation classifications to create maps of Cover Type and Structural Stages (describe in the next the section – Image Classification).
2) Statistical mapping a vegetation classification to create a map of Potential Vegetation Types (described in the Creating the Potential Vegetation Types Layer section above).

3) Developing the Successional Pathway Models (described in the Successional Modeling section below); and
4) Assigning ecological attributes to the vegetative triplets (used and described below in both the Fuel and Fire Characterization section and the Landscape and Assessment Modeling section).

For the rest of this document a hierarchical vegetation classification is defined as a systematic, hierarchal classification used to create three unique vegetation classifications based on plant succession and gradient modeling. These unique vegetation classifications are: Potential Vegetation Types Classification, Cover Types Classification, and Structural Stages Classification. These individual vegetation classifications will be used in defining and developing maps of Potential Vegetation Types through statistical analysis, and Cover Type and Structural Stages through remote sensing.

Developing a Hierarchical Vegetation Classification

We developed the Hierarchical Vegetation Classification because there is no perfect classification system, and we need one to meet the following LANDFIRE requirements: map-able, model-able, identifiable, and scaleable, in order for the project to be successful. **Map-able** means that only classes that can be delineated using the latest technologies in remote sensing and biophysical modeling will be mapped for the project. This will limit the number of classes that can be mapped consistently and accurately. **Model-able** means that the classes need to be able to fit into the Successional Pathway Models that are key to many of the LANDFIRE products. For cover types, this will limit them to classes of single species. **Identifiable** means that people need to be able to identify the classes in the field. Also, LANDFIRE personnel need to be able to key out the classes from information in the Reference Database. **Scalable** means that the classes need to be scalable to address different mapping scales used by managers and to allow links with existing classification. This will also allow managers the ability to step-down the classifications and mapping below the lowest LANDFIRE mapping scale, using the tools and methods developed for the project.

The Hierarchical Vegetation Classification and the individual classifications will be based on a combination of established vegetation classifications, extensive literature review, development of the Successional Pathway Models, the Reference Database, other mapping projects, and expert opinion. The Hierarchical Vegetation Classification is broken into three classifications: Potential Vegetation Types Classification, Cover Types Classification, and Structural Stages Classification (Table 3). The Cover Type

Classification was broken into five scalable mapping keys because of the complexity associated with the many different existing classifications systems (explained in the Developing Cover Type Classification section below). Relationships between individual classifications are one to many (e.g. several Cover Types can be in one or more Potential Vegetation Type), while relationships between the five mapping keys in the Cover Type Classification are one to one (e.g., a group of Cover Type Associations can only be in one Cover Type Alliance) (Table 3).

Table 3 – An example of the LANDFIRE Hierarchical Vegetation Classification.

Individual Vegetation Classifications	Mapping Keys	Descriptions	Examples (Forest – regular text; *Shrub – italic text*)
Potential Vegetation Types Classification	Potential Vegetation Types	Environmental conditions based on Biophysical Settings	Dry Douglas-fir *or*
Cover Types Classification *(Existing overstory vegetation or land use classes for non vegetation types)*	Cover Types Class	Growth form and structure of vegetation (similar to lifeform)	Forest *or Shrub*
	Cover Types Sub-Class	Delineates leaf phenology and types	Needle-leaved evergreen *or*
	Cover Types Alliance	A generic grouping of taxonomic characteristic with occasional grouping of specific genera based on individual species associations over large geographic areas.	Fir (based taxonomic) *or Chaparral (based on grouping of specific genera)*
	Cover Types	Based on a mixture of Association and Alliance	Douglas-fir (Association) *or Chaparral (Alliance)*
	Cover Types Association	A dominant overstory single species community type that covers a large geographic area.	Douglas-fir *or Chamise, Manzanita, Ceanothus spp., Salvia spp., etc…*
Structural Stages Classification	Structural Stages	Vegetation structural components	Closed Canopy – Tall Trees *or*

We will next describe each of the individual vegetation classifications: Potential Vegetation Types Classification, Cover Types Classification, and Structural Stage Classification. A complete description of about these classifications and the Hierarchical Vegetation Classification can be found in Appendix E.

Creating a Potential Vegetation Types (PVT) Classification

Potential vegetation types (PVT) are a site classification based on environmental factors like temperature, moisture, and soils (Pfister and others 1977). They usually described in terms of potential or "projected" climax vegetation (Arno and others 1985), were climax vegetation defined as a self-regenerating species that would occur on the site in the absence of disturbances like fire, grazing, and cutting (Daubenmire and Daubenmire 1968). Many authors have created PVT classifications: Daubenmire and Daubenmire (1968) for eastern Washington and northern Idaho; Pfister and others (1977) for Montana; and Steele and Hayes (1987, 1989, and 1993) for central Idaho. These classifications have focused on 1) successional theory, 2) the role of disturbance on community organizations and compositions, and 3) the use of indicator species in delineating the classification (Cook 1996). They provide a logical framework for studying succession (Arno and others 1985).

We will create the PVT classification from the Reference Database, an extensive literature review, other mapping projects, and expert opinion. We will start with existing national classifications (Schmidt and others 2002, Kuchler 1964), which we will then be revised based on regional (Quigley and others 1996) and local classifications (Pfister and others 1977). We will also incorporate the Reference Database, extensive literature review, and expert opinion to further refine the classification. The PVT Classification categories will be composed of environmental descriptor (i.e., dry, xeric, and mesic) with a dominant overstory species (i.e., Douglas-fir and Ponderosa Pine).

The PVT Classification will be mapped to the Biophysical Setting layer based on the Reference Database. The methods used to map PVT are described above in the Creating Potential Vegetation Types Layers section. The PVT Classification is critical for the development of the successional pathway models and mapping ecological attributes. A complete description of this classification can be found in Appendix E.

Creating a Cover Type (CT) Classification

Cover Types (CT) Classifications are based on the vegetation currently on the ground. They are generally delineated by the species with the most dominant overstory cover in the canopy. They have been known to incorporate land cover classes, which include both vegetation and non-vegetation classes (Homer and others 2002). Several authors have created CT Classifications, such as Society of American Foresters (SAF) Cover Types (Eyre 1980), Society of Range Management (SRM) Cover Types (Shiflet 1994), and The Nature Conservancies (TNC) National Vegetation Classification System (NVCS)

(Grossman and others 1998). Though these classifications are excellent for most projects, they do not work well for LANDFIRE for many reasons. First, these classifications have too many classes to map at the LANDFIRE mapping scale (about 55 western SAF types, 138 western SRM types, and 4,149 NVCS at the association level). It would be impossible to acquire enough plot data to represent each class needed to map these classifications across large geographic areas (western US, conterminous US). Second, several of the classes are composed of two or more species (e.g., SAF 250: Blue oak – Digger pine or SRM 509: Oak – Juniper Woodland and Mahogany – Oak) making them difficult to put into hierarchal classification structure (for SAF and SRM classification) and successional models. A hierarchal structure is important for creating maps at different map scales (national, regional, and local level). It also provides land managers the ability to revise the classification to a finer scale (project level). In addition, the mixed classes make it difficult to develop Successional Pathway Models, because the individual species can play different successional roles in the model. Lastly, these classifications mix environmental conditions with their description and stratification of floristic characteristics (e.g., cold deciduous woodland in NVCS). While it is important for communication purposes to incorporate environmental conditions when describing species communities, it does not work well for mapping and modeling purposes. By spatially breaking out environmental conditions from the existing vegetation, makes it both easier to map CT and CT can be used in more applications (e.g., modeling and vegetative triplet).

The LANDFIRE CT Classification is stratified into five mapping keys (or sub-categories) and is based on the NVCS (Grossman and others 1998) by using taxonomic, morphological, and ecological characteristics. Starting with NVCS (Grossman and others 1998), we modified the terminology and concepts to meet the needs of the project (map-able, model-able, identifiable, and scaleable) and to provide links to existing classifications (i.e., SAF, SRM). The sub-categories are: CT Class, CT Sub-Class, CT Alliance, CT, and CT Association, and are defined in Table 3. The CT Class and CT Sub-Class sub-categories are the coarsest level (with the fewest classes) and would be used to generate simple maps at the national or regional scale. The CT Alliance and CT sub-categories are the mid-scale level and would be used to create maps at the regional and local scale. CT Association sub-categories are the finest level and will not be used in creating maps for the project. This sub-category was included to create links to existing classifications (i.e., SAF and SRM) and to allow managers to create finer scale maps based on the data and models created in this project. The relationships between the sub-categories are one to one (e.g., a group of Cover Type Associations can only be in one Cover Type Alliance).

The CT sub-category is the lowest level we will use to create maps and models for this project; and it is composed of both CT Alliance and CT Associations classes because of the following reasons. First, CT Alliance is too broad to classify forestland for this project. For example, CT Alliance class *Pine* would be too broad to create the maps and models required for this project. However, CT Alliance works well for most grassland and shrublands. For example, we could never map all the species that occur in CT Alliance class *Chaparral*, because it would be impossible to acquire enough plot data to map each species; and these individual species rarely dominant a 30-meter-pixel (are minimum mapping unit). Second, CT Association classes are to fine for many grasslands and shrublands, because of the number of classes and the individual species rarely dominant a 30-meter pixel. But, CT Associations are the appropriate level for mapping most forestlands. If we use our example from above, a CT Alliance class of *Pine* would break out into a CT Association classes like *Ponderosa Pine*, *Lodgepole Pine*, and *Western White Pine*. Lastly, by classifying CT this way, we hope to avoid the favorite mapping species game, were some land managers feel it is important to map certain species, while others disagree. By creating a system that is hierarchical, we hope we can satisfy all land managers.

We will create the CT Classification from existing classification and maps, the Reference Database, an extensive literature review, and expert opinion. We will start with the national GAP mapping classification and refine it based SAF CT (Eyre 1980), SRM CT (Shiflet 1994), and NVCS (Grossman and others 1998) classifications. During this process, we will create a CT database with links to each of the classifications. We will next further refine the classification based on the Reference Database, extensive literature review, and expert opinion.

We will map the CT Classification by linking gradient modeling with remote sensing, by integrating the Biophysical Setting layer (describe above in the Creating the Biophysical Setting Layers section) with image process (described below in the Creating the CT Layers section). The CT Classification is critical for almost all phases of the project, including: the development of the successional pathway models, creating historical natural fire regimes, and mapping ecological attributes. A complete description of this classification can be found in Appendix E.

Creating a Structural Stage (SS) Classification

Structural Stages (SS) Classifications delineate developmental stages of a vegetative community from vegetative characteristics like age, height, canopy closure, and canopy structure. They are a key component in succession modeling and mapping ecological attributes. Arno and others (1985) classified forests based on the following stand characteristics: tree canopy coverage, average diameter at breast height of the dominant tree, basal area, and stand age. Quigley and Arbelbide (1997) used the processes approach based on growth, development, competition, and mortality to classified SS for the Interior Columbia Basin Ecosystem Management Project.

LANDFIRE SS Classification will be modeled on combinations of PVT, CT, canopy density and height classes. We create the SS Classification based on a statistical analysis of the Reference Database. We will further refine the classification based on existing classification, extensive literature review, and expert opinion. The SS Classification of CT Classes *Forest* and *Woodland* will be composed of four SS classes, based on a matrix of two canopy density classes and two height classes. The breaks used in dividing canopy density and height classes will vary for different combinations of PVT and CT. The SS Classification of non-forest CT Classes will be composed of only two classes of canopy density. Height growth was not included in these SS classes because most of it occurs swiftly in the first couple of years of plant life (grasslands and shrublands) and then quickly flattens out over time, making it difficult to incorparate in mapping and modeling. We will however include height classes for each combination of PVT, CT and non-forest SS classes, which will be used for modeling fuels and fire. Breaks used in dividing canopy density for non-forest SS classes, again will vary for different combinations of PVT and CT.

We will map the SS Classification from existing maps of PVT (describe above in Creating the PVT Layer section) and CT (describe below in the Creating the CT Layer section), and additional maps of canopy closure and height classes (describe below in Creating the Canopy Closure Layers and Creating the Height Class Layers sections). The SS Classification is critical for almost all phases of the project, including: the development of the successional pathway models, creating historical natural fire regimes, and mapping ecological attributes. A complete description of this classification can be found in Appendix E.

IMAGE CLASSIFICATION

Critical to nearly all phases of LANDFIRE is an accurate portrayal of the current characteristics of vegetation at a resolution appropriate for this analysis. In this section, we will describe the remote sensing methods used to create layers of Cover Type (CT), Canopy Closure, and Height Classes, by linking gradient modeling with remote sensing. These layers combined with PVT, will be used to create the Structural Stage (SS) layer. We will also discuss the potential use of other satellite data and methods and the potential for automating the remeasurement process.

The vegetation classification (keys) used to create layers of CT and SS have been described above in the VEGETATION CLASSIFICATION section. Maps of CT and SS are extremely important in almost all phases of this project. Further details about all methods described in this section can be found in Appendix F.

Acquiring and Preprocessing Satellite data

Cover Types and vegetative structure (canopy closure and height classes) layers will be derived using Landsat 7 Enhanced Thematic Mapper Plus (ETM+) images, Biophysical Setting layer, and relevant ancillary data. With a spatial resolution of 30-meters, Landsat data has been widely used for vegetation mapping at regional and national scales (Fuller and others 1994, Homer and others 1997, Vogelmann and others 2001b). For the two prototype mapping zones, ETM+ images have been or will be acquired on three different dates over the time period between 1999 and 2001 to capture vegetation dynamics of a growing season and to maximize land cover type separability (Yang and others 2001). We will be geometrically and radiometrically corrected the image using standard methods (Irish 2000). Terrain correction using USGS 1-arc second National Elevation Dataset will be performed to improve geolocation accuracy. We will convert raw satellite digital numbers to at-satellite reflectance for the six ETM+ reflective bands, and to at-satellite temperature for the thermal band according to Markham and Barker (1986) and the Landsat 7 Science Data User's Handbook (Irish 2000). We will use at-satellite reflectance based coefficients to calculate Tasseled-cap brightness, greenness and wetness (Huang and others 2002b), which have been found useful for vegetation characterization (Cohen and others 1998).

Creating the Cover Type (CT) Layer

Many classification algorithms have been developed for deriving vegetation cover type from satellite imagery (Cihlar 2000, Hall and others 1995). In this project, we will create the Cover Type layer (defined in the vegetation classification) by using a classification tree algorithm, followed by knowledge-based modeling, on processed satellite imagery, Biophysical Settings, and relevant ancillary data. We selected the classification tree methods for the following reasons. First, as non-parametric classifiers, they are more appropriate for large area mapping than parametric methods (supervised and un-supervised classification methods). Second, the models can be trained hundreds of times faster than some other non-parametric classifiers like neural networks and support vector machines (Huang and others 2002a). Yet, it is comparable to or only marginally less accurate than those methods (Friedl and Brodley 1997, Huang and others 2002a). Third, the classification tree models explicitly output classification logics that can be interpreted and incorporated in expert systems for further analysis. Whereas neural networks and support vector machines work like "black boxes", with their classification logics difficult to interpret or simply "invisible". Lastly, classification tree methods have been successful in modeling the general cover types and detailed forest classes in mapping zone 16 (Homer and others 2002, Huang and others 2001a).

We will develop the Cover Types layer by using a hierarchical and iterative set of classification models, with the first model separating more general land cover types and subsequent models separating more detailed cover types. Specifically, general cover types at the Cover Type Class (lifeform) level will be simply copied from the land cover dataset developed through the Multi-Resolution Land Characterization (MRLC) 2000 program, a multi-agency national land cover mapping effort (Homer and others 2002). Forest, shrub and grass pixels in this general classification will then be modeled separately using one or more classifiers to define the Cover Type Classification to progressively more detailed levels such as Cover Type Alliance level or Cover Type level (see Table 3). The Reference Database, Biophysical Settings layer, and other ancillary data layers will be extensively consulted to guide the classification. While the classification tree method has been very successful in deriving forest classes in mapping zone 16 (Huang and others 2001a), we anticipate more extensive use of knowledge-based models taking advantages of ancillary data, Biophysical Settings layer, and possibly vegetation seasonal matrices of MODIS data in deriving rangeland classes at the required details. We will further discuss the use of MODIS data below.

Creating the Canopy Closure Layer

Existing methods for estimating canopy closure from satellite imagery include physically based models, spectral mixture models and empirical models. Though often considered neither based on physical mechanisms nor the most sophisticated methods, empirical models have been found most successful than the other two groups of models in large area applications (Iverson and others 1994, Zhu and Evans 1994). We will use two empirical methods – regression tree and a *k*-nearest neighbor (KNN) method to model the relationships between canopy closure and satellite data. When compared to linear regression, both regression tree and KNN have the advantage of being able to approximate complex nonlinear relationships. We have successfully derived tree canopy closure for mapping zone 16 and several other areas using the regression tree method (Huang and others 2001b). KNN was found useful for deriving a number of forest attributes, including stand density, timber volume and cover type (Franco-Lopez and others 2001, Makela and Pekkarinen 2001). While we anticipate that the regression tree and KNN methods are useful for modeling shrub and grass percent cover, we will explore other methods, including use of ETM+ based vegetation indices (Wylie and others 2002) and vegetation seasonal greenness matrices derived from MODIS and AVHRR data (Reed and others 1994).

Creating the Canopy Height Class Layer

We will use regression tree and KNN methods (both described above) to model vegetation height. We will first model vegetation height as a continuous variable and classify it to height classes as defined in the Structural Stage Classification. We have achieved encouraging results in modeling tree height from ETM+ image using the KNN method in an initial test. In the cases of shrub and grass height classes, it is not yet clear how successful the techniques can be. An alternative technique would be to sample sufficient amount of field reference data including height measurements. Then the sampled height distribution will be assigned to segmented shrub or grass communities, assuming these communities have unique but uniform average height given their specific biophysical settings.

Creating the Structural Stages (SS) Layer

We will create the Structural Stages layer by assigning SS classes to combinations of PVT, CT, Canopy Closure, and Height Classes layers. SS assignments are based on the SS Classification created from a statistical analysis of the Reference Database (described above in Creating the SS Classification section). Though the assignment of the SS Classification to these layers should be straight forward, modifications probably will be required.

Potential Use of Other Satellite Data and Methods

In addition to Landsat 7 ETM+ images, other satellite data may provide complementary information on vegetation status. We are specifically interested in Lidar data and data from ASTER, SAR and MODIS. Airborne Lidar was found very effective for deriving forest structure information (Lefsky and others 1999, Lefsky and others 2001). ASTER has more short wave and thermal infrared bands than ETM+, and has three visible/near infrared bands with a spatial resolution of 15m. While MODIS has coarser spatial resolutions than ETM+, its fine temporal resolution allows characterizing vegetation based on inter- and intro-annual variations. SAR data is of interest for this study because it provides complementary information to optical remote sensing data. Recent studies demonstrated encouraging relationships between SAR interferometry signals and vegetation type and structure (Santoro and others 2002, Wegmuller and Werner 1995).

While classification tree, regression tree, KNN and knowledge-based methods are selected as the primary methods for deriving vegetation characteristics, we will also explore other advanced methods that may be appropriate for regional vegetation characterization, and will seek expert knowledge from external experts.

Potential for Automating the Remeasurement Process

Because vegetation cover often changes over time, the above derived vegetation type and structure layers need to be updated periodically. This not only requires acquiring new Landsat imagery, but may also necessitate re-measuring some or all field reference data points. Fortunately, only non-forest reference data points need to be re-measured, as forest inventory plots are updated every 5 to 10 years through the Forest Service FIA program (Smith 2002). We will investigate whether robust models can be used to automatically or semi-automatically update vegetation cover type and structure layers in a five or ten year interval.

SUCCESSIONAL MODELING

In this section, we will discuss the methods used to develop Successional Pathway Models and run the LANDSUM simulation model. We will use these models to create maps of historical natural fire regimes and fire regimes condition classes; and to evaluate ecosystem status and fire hazard and potential status. Maps (and classifications) of Potential Vegetation Types (PVT), Cover Types (CT), and Structural Stages (SS) created by integrating gradient modeling with remote sensing can directly be used in successional pathway modeling. Descriptions of PVT, CT, and SS can be found in the VEGETATION CLASSIFICATION section above.

Succession pathways models incorporate plant succession with disturbances like fire, thinning, and grazing. It is the link between several vegetation communities or successional classes (describe by combination of CT and SS) along a network of multiple paths (developed for each PVT) based on the development of biotic communities following disturbances. The transition times required to move from one succession class to another will dictate the status of ecosystem development. There is a brief discussion describing successional pathway modeling in the BACKGROUND section above. Since successional pathways are key in developing several LANDFIRE products, considerable effort will be spent on this task to ensure accurate and reliable successional pathway diagrams are developed in a timely and efficient manner.

Developing Successional Pathway Models

We will develop successional pathway models using a computer program called the Vegetation Dynamics Development Tool (VDDT) (Beukema and Kurtz 1995). This program allows efficient model building and refinement in a user-friendly environment. First, we will create a succession pathway diagram that identifies those succession classes that are present in a given PVT. This diagram will identify all pathways of development important in a PVT, including those disturbance pathways resulting from fire and other major disturbances. These diagrams will be based on a thorough review of the literature, the Reference Database, evidence from other modeling efforts, and expert evaluation from various areas of the country.

Perhaps the most difficult parameters to quantify in the succession pathway models are succession transition times and disturbance probabilities. We will quantify transition times using a simulation approach that integrates a wide variety of empirical and process-based ecosystem models. First, we will use the Forest Vegetation Simulator (FVS), an empirical individual tree growth and yield model, to grow individual stands that describe a succession class and identify the time needed to advance to the next succession class. Stage (1998) did this for the Columbia River Basin Succession Model (CRBSUM) pathways during the Interior Columbia Basin Ecosystem Management Project effort (Quigley and others 1996, Keane and others 1996). We will design and then program classification keys to identify CT and SS from those attributes simulated by FVS (e.g. diameter and height by species). In addition, in geographic areas where FVS has not been implemented, we will also use several gap-phase succession models such as

FIRESUM (Keane and others 1990) and Zelig (Urban and Miller 1996). These models will be used to quantify transition times for all remaining forest PVTs using the same keys developed for FVS. Unfortunately, FVS and gap-phase models do not work especially well or do not exist for shrublands, grasslands and a few forest ecosystems. In these cases, we will collect those fine-scale models that may apply to our purposes or we will solicit help from local ecologists to quantify transition times from their vast experience and any available literature.

The quantification of fire probabilities in fire pathways of each succession model will be slightly easier. These probabilities will be taken from the existing fire regimes maps (Schmidt and others 2002, Morgan and others 1996), detailed fire history studies (Heyerdahl and others 1995) collected in the Reference Database, the National Fire Occurrence spatial datasets (Schmidt and others 2002), and extensive literature search. However, many ecosystems are not governed by fire, especially in the eastern US. For example, insects and disease or wind-throw are major disturbances in the northeast and north central US. These disturbances must be included in the succession pathway diagram to integrate all other factors into successional development to provide accurate condition evaluations. The probabilities of these non-fire events will be garnered from the literature and expert opinion. We will not simulate every possible disturbance within a PVT, but rather we will identify only those disturbances that profoundly affect the successional cycle at a scale appropriate to this project. For the prototype, we will first develop pathways for the mapping zones and then expending to the western US.

We will use Successional Pathway Models to create maps of historical natural fire regimes and fire regimes condition classes. Successional Pathway Models are also required input for the LANDSUM model; which we will use to evaluate ecosystem status and fire hazard and potential status. A complete description of the methods used to develop Successional Pathway Models can be found in Appendix G.

Modifying and Using the LANDSUM Landscape Simulation Model

The LANDscape SUccession Model (LANDSUM) is a spatially explicit vegetation dynamics simulation C++ program wherein succession is treated as a deterministic process and disturbances (e.g., fire, insects, and disease) are treated as a stochastic processes (Keane and others 1997). LANDSUM simulates succession within a patch (adjacent similar pixels) or polygon using the multiple pathway fire succession modeling approach presented by Kessell and Fischer (1981). This approach assumes all pathways of successional development will eventually converge to a stable or climax plant community called a PVT.

LANDSUM has been use to estimate historical range and variation of landscape patch dynamics for four watersheds in the northern Rocky Mountains and Cascades (Keane and others 2002b). It has also been used to develop fire regimes for a watershed in the Selway Bitterroot Wilderness located in the mountains of central Idaho (Keane and others 2003). An early version of LANDSUM, called CRBSUM, was used to predicate future management scenarios for the Interior Columbia Ecosystem Management Project (Keane and others 1996).

We will use LANDSUM to map historical natural fire regimes and to evaluate ecosystem status and fire hazard and potential status on a landscape scale based on these research projects. We will first create a user-friendly version of the program. Next, we will standardize the inputs and outputs of the model to match the Successional Pathway Models and PVT, CT, and SS layers developed for the project. Lastly, we will test the model to determine the appropriate scale to model landscapes efficiently, while meeting the objectives of the project.

A complete description of the methods used to modify and run LANDSUM can be found in Appendix H.

FUEL and FIRE CHARACTERIZATION

In this section, we will discuss the methods used to create maps that characterize fire regimes, fuels, and fire. These products include maps of Historical Natural Fire Regimes, Fire Regimes Condition Classes, Fuel Models, Fuel Loading Models, and FARSITE data layer inputs; and the FIREHARM model used create maps additional maps that characterize fuels and fire. The creation of Historical Natural Fire Regimes and Fire Regimes Condition Classes maps will be completed by linking successional modeling with gradient modeling and remote sensing integration. We will use Successional Pathway Models and LANDSUM with the Biophysical Setting, Potential Vegetation Types (PVT), Cover Types (CT), and Structural Stage (SS) layer (all described above in different sections) to create the Historical Natural Fire Regimes and Fire Regimes Condition Classes maps.

The creation of Fuel Models, Fuel Loading, and FARSITE data layer inputs maps will be completed integrating successional theory with mapping ecological attributes to the vegetative triplets. We will use PVT, CT, SS layers with the Reference Database to create these maps. The creation of the FIREHARM model will be based on a compilation of existing fuel and fire equations derived for fire behavior, fire effects, and fire danger. To run FIREHARM will require maps of Fuel Models and Fuel Loadings along with the Biophysical Setting layers and the DAYMET weather database. FIREHARM will be used to evaluate fire hazard and potential status by comparing LANDSUM historical simulation runs with existing conditions. These methods will be described in more detail in the LANDSCAPE and ASSESSMENT MODELING section below.

Creating the Historical Natural Fire Regimes Layer

Fire regimes are often defined in terms of fire frequency, size, pattern, intensity, and severity (Heinselman 1981, Agee 1993). They define the nature of fires occurring over an extended period-of-time (Brown 1994) that characterize the fire history of an ecosystem (Heinselman 1981, Schmidt and others 2002). Historical natural fire regime data are not meant to be exact reconstruction of historical conditions, but rather reflect typical fire frequencies and effects that evolved without fire exclusion (Hardy and others 1998). These historical conditions, traditionally defined as conditions existing before extensive pre-Euro-American settlement, provided a reference conditions to compare to current conditions (Schmidt and others 2002).

Building on the national historical nature fire regime work of Hardy and other (2001), we will define fire regime in terms of frequency and severity. We will start with the historical natural fire regime definitions created by Hardy and other (2001) (Table 4). Then we will potential stratified these classes into sub-classes to account for important fire history patterns that may be needed to produce other LANDFIRE products or management objectives. These stratified sub-classes will be based on fire history databases (Heyerdahl and others 1995) and existing historical natural fire regime maps (Morgan and others 1996).

Based on Hardy and other (2001), we will define fire frequencies as the average number of years between fires, and severity as the effect of the fire on the dominant overstory vegetation. The dominant overstory vegetation can be forest, shrub, or herbaceous vegetation. Low severity fires, are fires resulting in the survival of over 70% of the basal area and over 90% of the canopy cover of the overstory vegetation (Morgan and others

1996). Mixed severity fires, are fires with moderate effects on the overstory caused by different severities occurring during the fires and resulting in mixed mortality and irregular spatial mosaics (Smith and Fischer 1997). Stand replacement fires are fires where less than 20% of the basal area or less than 10% of the overstory canopy cover remains after the fire (Morgan and others 1996).

Table 4 – Historical Natural Fire Regimes developed by Hardy and others (2001).

Historical Natural Fire Regime	
Classes	Description
I	0-35 years; Low Severity
II	0-35 years; Stand Replacement
III	35-100+ years; Mixed Severity
IV	35-100+ years; Stand Replacement
V	200+ years; Stand Replacement

Many authors have mapped fire regimes at different scales. At the course scale, Morgan and other (1996) mapped fire regimes for the Interior Columbia River Basin Assessment Project using expert opinion and succession pathway decision rules. Hardy and others (2001) created historical natural fire regimes for the conterminous US from a combination of ecological-hydrological units and PVT map. And, Frost (1998) developed pre-settlement fire frequency regions for the conterminous US, using fire history studies and a map of land surface forms.

At the fine scale, Lineback and others (1999) created a fire regimes from both fire history records and fire perimeters. This methodology requires extensive field sampling and detailed fire perimeter atlases, which is not common in most areas. At the mid to fine scales, several authors have used statistical or simulation modeling to create fire regimes from fire history data (Keane and Long 1997, Long 1998, McKenzie 1998). Along these lines, Rollins and others (2003) linked remote sensing, ecosystem simulations, and gradient modeling to map fuels and fire regimes for the Kootenia River Basin in northwest Montana. Lastly, Keane and others (2003) evaluated the challenges of mapping fire regimes by comparing three different strategies (classification, statistical analysis strategies, and simulation modeling) and three approaches (stochastic, empirical, and physical) for mapping fire regimes.

For this project, we will map Historical Natural Fire Regimes based on three lines of exploration: empirical, expert system, and simulation modeling; by building on the work of Keane and others (2003) and Rollins and others (2003) described above. Each methodology (or approach) will be reviewed to determine the most efficient and accurate way to expend the mapping effort for the conterminous US. To complete and evaluate each of these approaches, we will link the Reference Database with combinations of: the Biophysical Setting layer; maps of PVT, CT, and SS; and Successional Pathway Models and LANDSUM simulation model (all described in different sections above). One of the databases in the Reference Database will consist of a compilation of fire history and fire assessment studies (e.g., Agee and Heyerdahl 1998). This database, called the Fire Regime Database, will be used to feed the different approaches for mapping historical natural fire regimes.

For the empirical and expert system approach, we will use advanced statistical techniques to predict fire regime similar to the methods and layers used to create the Biophysical Settings layer and the PVT map. First, we will assign all biophysical information (layers used to map the Biophysical Settings) to each record in the Fire Regimes Database. This will be accomplished by linking the geographical coordinates in the Fire Regime Database to the appropriate pixels in the biophysical layers. By adding attributes of biophysical characteristics in the Fire Regime Database, we can predict fire regimes using either an empirically or expert system. Next, we will explore using multivariate statistics coupled with regression tree and neural networks analysis techniques, to develop algorithms to predict historical natural fire regimes. We will use those biophysical layer attributes assigned to Fire Regime Database as independent variables, and a classification of the historical natural fire regimes in Table 4 as dependent variables, to create the predictive equations. Instead of computing fire regime for each 30-meter pixel, we will assign a fire regime to each Biophysical Setting polygon to reduce computer time.

For the simulation modeling approach, we will use the Successional Pathway Models in LANDSUM (with maps of PVT, CT, and SS) and VDDT simulation models. We will first use VDDT to test the Successional Pathway Models based on the Fire Regime Database, by running VDDT for a thousand years. Next, we will evaluate and modify the probabilities and succession times in the pathways to obtain a more accurate predictor of fire regimes from the Successional Pathway Models. This will also provide us with an estimate of historic composition of CT and SS for each PVT, which can be used in mapping fire regime condition classes, and evaluating ecosystem statues and fire hazard and potential status. Next, to create spatial layer of historical natural fire regimes, we will run LANDSUM, with the modified successional pathways, for a thousand years using a similar approach described by Keane and others (2003). We will then evaluate and modified these runs based on the following: Fire Regime Database, Reference Database, historic composition of CT and SS created above, and expert opinion.

We will then evaluate the different approaches to create historical natural fire regimes, based on accuracy, efficiency, and use in creating other LANDFIRE products and management objectives. The final Historical Natural Fire Regime map (one of LANDFIRE final products) will be used to create Fire Regime Condition Classes, and to evaluate ecosystem status and fire hazard and potential status maps (described in sections below). For a complete description of the methods and process used to create Historical Natural Fire Regimes, see Appendix I.

Creating Fire Regime Condition Classes Layer

Fire Regime Condition Classes (Table 5) is defined as the departure from historical natural fire regimes resulting in alterations to key ecosystem components such as species composition, structural stage, stand age, and canopy closure (Schmidt and others 2002). This departure may have been caused by one or more of the following activities: fire exclusion, timber harvesting, grazing, introduction and establishment of exotic plant species, insects or disease (introduced or native), or other past management activities (Schmidt and others 2002). Hardy and others (2001) mapped historical natural fire regimes at the coarse scale for the conterminous US, by assigning condition classes to generic successional pathway models that were linked to several spatial layers.

Though the methodology used, by Hardy and others (2001), to map Fire Regime Condition Classes worked well at the coarse scale, it will not work at the mid to fine scale (Hann and others (in prep)). This is because a certain percent of the vegetative structure used to represent Fire Regime Condition Class 2 or 3, could have occurred historically. For example, in a Dry Douglas-fir PVT with a frequent low intensity historic fire regime, a small percent of the landscape was historical represented by mature, dense, Douglas-fir stands; instead of mature to over-mature, open spaced ponderosa pines. Using the coarse scale methods, all these Douglas-fir stands would be assigned Fire Regime Condition Class 3, when we know a small percent were in Fire Regime Condition Class 1, because they could have occurred historically (Hann and others (in prep)).

To resolve this problem, we will map Fire Regime Condition Classes based on analyzing vegetative compositions generated from VDDT runs describe above in Historical Natural Fire Regime section. We will statistically compare these runs to the Fire Regime Database and other Reference Databases. From this analysis, we will map Historical

Natural Fire Regimes based on vegetative compositions found within each combination of Biophysical Setting and PVT mapping unit. We will explore using different mapping procedures like assigning Fire Regime Condition Classes to primary colors (such as red, green, and blue) to develop maps of multiple shades that represent different compositions of these classes. Lastly, we will explore using different attributes generated by FIREHARM (described below) and methods described in LANDSCAPE and ASSESSMENT MODELING section (described below) to map indices that reflect Fire Regime Condition Classes.

Table 5 – Fire Regime Current Condition Class[a] descriptions

Condition Class	Fire Regime	Example Management Options
Condition Class 1	Fire regimes are within an historical range and the risk of losing key ecosystem components is low. Vegetation attributes (species composition and structure) are intact and functioning within an historical range.	Where appropriate, these areas can be maintained within the historical fire regime by treatments such as fire use.
Condition Class 2	Fire regimes have been moderately altered from their historical range. The risk of losing key ecosystem components is moderate. Fire frequencies have departed from historical frequencies by one or more return intervals (either increased or decreased). This results in moderate changes to one or more of the following: fire size, intensity and severity, and landscape patterns. Vegetation attributes have been moderately altered from their historical range.	Where appropriate, these areas may need moderate levels of restoration treatments, such as fire use and hand or mechanical treatments, to be restored to the historical fire regime.
Condition Class 3	Fire regimes have been significantly altered from their historical range. The risk of losing key ecosystem components is high. Fire frequencies have departed from historical frequencies by multiple return intervals. This results in dramatic changes to one or more of the following: fire size, intensity, severity, and landscape patterns. Vegetation attributes have been significantly altered from their historical range.	Where appropriate, these areas may need high levels of restoration treatments, such as hand or mechanical treatments, before fire can be used to restore the historical fire regime.

[a]Fire Regime Current Condition Classes are a qualitative measure describing the degree of departure from historical fire regimes, possibly resulting in alterations of key ecosystem components such as species composition, structural stage, stand age, canopy closure, and fuel loadings. One or more of the following activities may have caused this departure: fire suppression, timber harvesting, livestock grazing, introduction and establishment of exotic plant species, introduced insects or disease, or other management activities.

The final Fire Regime Condition Class map (one of LANDFIRE final products) will be used to evaluate ecosystem status and fire hazard and potential status maps (described in sections below). For a complete description of the methods and process used to create Fire Regime Condition Class, see Appendix J.

Creating the Fuel Models Layer

Fuels are defined as the characteristics of live and dead biomass (e.g., mass and density) that contributes to the spread and intensity of wildland fire (Burgan and Rothermal 1984). Wildland fuels are the one parameter affecting wildland fire that humans can control (Rothermel 1972). A generalized description of fuel properties is often used to characterize fuels for an area, because of the difficulty in describing composition and physical characteristics of fuels (Anderson 1982, Sandberg and others 2001). These characterizations, referred to as fuel models, represent the typical fire behavior or fuel condition for an area (Andrews 1990). Fuel models are the single most important input for the current set of fire behavior simulation models (Finney 1999).

We will refine and revise the existing Anderson's (1982) fuel models for this project. Though widely used, Anderson's (1982) fuel models are limited for the following reasons. First, these fuel models are difficult to key out or identify from existing plot data; or to assess in the field. Second, these fuel models don't take into account the complete range of fire behavior characteristics defined by specific ecosystems (e.g., rangelands and shrublands) through out the conterminous US. Lastly, these fuel models do not take into account the changing fuel dynamics created by the introduction of exotics. To create the new fuel models, we will modify Anderson's (1982) fuel models based on: an extensive review of the literature; a compilation of databases that delineate fuel characteristics; and through a series of expert panels.

We will map these new fuel models, called Fire Behavior Fuel Models, based on successional theory to map ecological attributes to the vegetative triplets. We will use a couple of different statistical analysis procedures and expert opinion to assign Fire Behavior Fuel Models to unique combinations of PVT, CT, and SS (vegetative triplet) based on the Reference Database. By linking Fire Behavior Fuel Models to the vegetative triplet, we can create a map of Fire Behavior Fuel Models, which is one of the LANDFIRE final products. Based on this link to the vegetative triplet and the LANDSUM simulation model, we will create maps of Fire Behavior Fuel Models for different periods-of-time (past and future) that will be used in evaluating fire hazard and potential status. Fire Behavior Fuel Models are one of the required inputs for the FARSITE model.

A complete description of the methods used to define and create Fire Behavior Fuel Models has been included in Appendix K.

Creating the Fuel Loading Models Layer

Another system for characterizing fuels is the Fuel Characterization Class (FCC) developed by Ottmar and others (1998) and revised by Sandberg and others (2001). This system is a comprehensive description of all components and characterizations found in a fuelbed, including loadings by size class (Sandberg and others 2001). These fuel descriptions are important for the next generation of fire behavior models and for current and future fire effects models.

We will create Fuel Loading Models by first summarizing fuel loadings data from the FCC database (Sandberg and others 2001) to unique combinations of PVT, CT, and SS (vegetative triplet), based on several statistical procedures. Next, we will augment these summaries based on additional fuel loading data in the Reference Database and in the national fuel photo series database (Ottmar and others 1998); extensive literature review; and expert opinion. Like with the Fuel Models layer, we will then be able to map past, present, and future Fuel Loading Models, by using the vegetative triplet and the LANDSUM simulation model.

The Fuel Loading Models layer is one of the LANDFIRE products and will be used in the next version of FARSITE. It will also be used in this project to evaluating fire hazard and potential status. A complete description of the methods used to define and create Fire Loading Models has been included in Appendix K.

Creating the FARSITE Data Layers

The last series of fuel attributes we will create from the vegetative triplets are some of the input data layers required for FARSITE (Keane and others 1998a). FARSITE (Fire Area Simulator) is a spatial fire behavior simulation model that requires three types of data: weather, topography, and fuels information (Finney 1998). The weather information will not be developed in this project, since most FARSITE runs are based on the current weather conditions at the time of the fire. The topography information (slope and aspect) will come from the 30-meter DEM described in the Ancillary Data section. The fuels information (fuel models, crown bulk density, and height to live crown) will be compiled from several data sources and will be linked using the vegetative triplets (Keane and others 1998a). Fuel models will come from this project and already describe above. Crown bulk density will come from a comprehensive database compiled by Reinhardt and Scott (in prep) based on an extensive field inventory project. The other fuels information will come from the Reference Database, existing studies, and expert opinion. Most of the fuel information required for FARSITE will be mapped at a mid-scale accuracy, instead of being mapped at the preferred fine scale accuracy (both are based on 30-meter pixel size). This may require FARSITE modelers to further calibrate the inputs before getting reasonable predictions.

A complete description of the methods used to create the FARSITE data layers has been included in Appendix K.

Creating the FIREHARM Model

The FIRE HAzard Rating Model (FIREHARM) integrates weather, fuels, and vegetation to produce a science-based assessment of fire potential and fire hazard. The program computes fire characteristics based on 18 years of weather records. The fire characteristics are based on three categories: fire danger, fire behavior, and fire effects. The fire danger indices include spread component, energy release component, burning index, and ignition component. The fire behavior indices include flame length, fire line intensity, spread rates, and crown fire potential. And the fire effects indices include fuel consumption, tree mortality, soil heating, and smoke emissions.

The outputs are a list of fire event probabilities or characteristics that are controlled by the user. These controls include a user defined minimum threshold value, like outputting probabilities were flame lengths are 1-meter or greater. A user specified date range that allow user to calculate probabilities for a specific time of year, like between julian date 100 and 300. And lastly, the user can determine if they want the calculations based on yearly weather data calculated annual (a summary for each year) or daily. An example of standard output calculated for a given area (or polygon) would look this: 0.26 probability of flame lengths above 1 meter during julian date 100-300 from 18 years of daily weather data.

In this project, we will finish the development of FIREHARM by incorporating algorithms from several other existing models. The inputs to run FIREHARM include: Biophysical Setting, Fuel Model, and Fuel Loadings Model layers, and the DAYMET weather database. All inputs have been created as part of LANDFIRE, and are described in different sections above. FIREHARM will be designed to run on polygons delineated by the Biophysical Setting layer.

FIREHARM is one of the LANDFIRE products. We will use it to create maps used to evaluate fire hazard and potential status. FIREHARM could also be used to evaluate and prioritize the wildland urban interface, by looking at fire behavior characteristics like flame length, spread rate, and crown fire potential. Alternatively, it could be used to evaluate watersheds based on fire effects characteristics like tree mortality, soil heating, and fuel consumption. A complete description of the FIREHARM model has been included in Appendix L.

LANDSCAPE and ASSESSMENT MODELING

In this section, we will develop methods used to compare historical conditions with current and potentially future conditions. The comparisons are divided into two groups: ecosystem status and fire hazard and potential status. Ecosystems status will be used to evaluate mostly vegetative characteristics, while fire hazard and potential status is specific to fire and fuel characteristics (both explained in the following sections). These evaluation will be based on a single measure of departure based on statistical derived indexes using both proportion statistics and complex algorithms that incorporate many vegetative, fuel, and fire characteristics.

We define landscape and assessment modeling to be the combination of landscape modeling used to create vegetative, fuels, and fire characteristics at different periods of time (historical, future); with assessment modeling used to create departure indices based on statistical analysis of these characteristics at different periods of time. Landscape modeling is based on plant succession. We will use landscape and assessment models to evaluate the current-status of an ecosystem, stand, or region based on the degree of departure from historical conditions (i.e., pre-European settlement). Historical conditions are based on the central tendency of the historical successional cycle. This evaluation assumes that historical conditions approximate a reference condition, which can be used to compare current conditions.

To accomplish this goal, we will link succession modeling with the layers created from the integration of gradient modeling with remote sensing, and with the layers created by mapping ecological attributes to the vegetative triplet. The following layers and models have been created for this project and are described in different sections above. For landscape modeling, we will use LANDSUM simulation model with maps of Potential Vegetation Types (PVT), Cover Types (CT), and Structural Stages (SS); and VDDT (non-spatial) simulation model. Both LANDSUM and VDDT are based on the Successional Pathway Models. Outputs of these models will be used to create maps that characterize vegetative (CT, SS), fuel and fire (Fuel Models, Fuel Loading Model, FIREHARM outputs), for different periods-of-time (past and future). Landscape modeling is used to simulate desired systems at desired scales.

For assessment modeling, we will develop a statistical models used to evaluate these characteristics at different periods-of-time based on departure from historical conditions or future conditions. First, we will perform a detail analysis and summary of the landscape modeling outputs to create reports of standard statistics. Next, we will then create statistical procedures to compare current conditions with simulation results. These statistical procedures will include: 1) the development of a statistical test to evaluate degrees of departure from reference conditions; 2) develop a statistical test of departure for comparison purposes, and 3) develop an index of departure for mapping descriptive purposes. The results of these statistical procedures will be used to evaluate departure for ecosystem status and fire hazard and potential status. A complete description of these methods can be found in Appendix M.

Creating the Ecosystem Status Index

Ecosystem status will be a deviation of an ecological characteristic from the range of historical conditions. These ecological characteristics include: species composition, vegetation structure, fuel characteristics, and landscape metrics. As described above, ecosystem status is a statistical comparison of current conditions and historical conditions. We will use the outputs of the VDDT model based on the Successional Pathway Models to quantify the central tendency of historical successional cycles to create historical conditions. The VDDT (Vegetation Dynamics Development Tool) model provides a vehicle for the construction of integrated pathways of succession classes and then allows the simulation of these pathways over a finite number of land units. Succession classes are based on combination of CT and SS. We will use VDDT to compute the range and variability of the proportion of a landscape in each succession class. This will provide a baseline to evaluate departure from historical conditions.

The general procedure will be to run the VDDT model for each PVT for 1,000 years. The mean and standard error of the proportion each succession class will be calculated across every year in the 1,000-year run. This distribution of succession class proportions will allow the quantification of the comparison of VDDT results with any succession class map (combination of PVT, CT, SS) at any scale. Next, we will develop an algorithm that computes the degree of departure of a given pixel, stand, watershed, or region from the expected succession class distribution using the proportion statistics. We can also compute the same statistic for a watershed, a National Forest, or an entire Region.

For example, a 1,000-yr VDDT run for a *Dry Douglas-fir Potential Vegetation Type (PVT)* might have 50% pixels in *Ponderosa Pine Cover Type (CT)* with *Open-Stand-of-Tall-Trees Structural Stage (SS)*, 25% in *Douglas-fir CT* with *Closed-Stand-of Tall-Trees SS*, and 25% in *Ponderosa Pine CT* with *Closed-Stand-of-Small-Trees SS*. A mapped polygon of current conditions (collection of pixels) might be classified to *Ponderosa Pine CT* with *Closed-Stand-of-Small-Trees SS*, which might yield a departure score of 31 using our algorithm. Now, say a watershed composed of solely *Dry Douglas-fir PVT* and has 10% *Ponderosa Pine CT* with *Open-Stand-of-Tall-Trees SS*, 80% *Douglas-fir CT* with *Closed-Stand-of Tall-Trees SS,* and 10% *Ponderosa Pine CT* with *Closed-Stand-of-Small-Trees SS*. We will then use our algorithm to compute a departure score of 70. This algorithm could be as simple as a similarity analysis (Gauch 1982) or as complex as a logistic regression or departure analysis.

The ecosystem status index will be based on assessment modeling (described above) which is used to create the algorithms. The algorithm's design criteria are not final because we must eventually integrate other ecosystem characteristics (e.g., insects, disease, and fuels) into this assessment. This integration of other ecosystem characteristics will be defined by fire and land managers, not the cadre of scientist and support people involved in the project. These support people will assist management in the decision process, but ultimately, it is incumbent on management to design the index. On smaller landscapes, we can also generate these types of departure indices using the LANDSUM model.

An advantage of using output from a succession model as baseline reference for comparisons is that new fire probabilities and silvicultural treatments can be added to form a new baseline that integrates management into ecosystem status. The complete return of historical conditions is impossible for the conterminous US, so it seems more plausible to construct baseline references that incorporate human-caused disturbances such as grazing, settlement, and harvesting, into the calculation. The process that we will design for rating ecosystem status will have the ability to use any simulated scenario as a baseline condition so that we can adapt our management strategies to account for future concerns, such as global climate warming, new exotic diseases, and weeds.

A complete description of these methods can be found in Appendix M.

Create the Fire Hazard and Potential Status Index

Fire Hazard and Potential Status is a group of indices derived by fire managers used to compare historical conditions with current conditions for specific fire and fuel characteristics. They provide a way to evaluate the likelihood of a fire to burn with specific characteristics in fire behavior, fire danger, fire effects, and fire regimes. These indices are developed and calculated from a compilation of FIREHARM outputs, fuel models, and fuel loadings. They provide a simple way for fire managers to evaluate key attributes based on compilation of complex variables.

To create Fire Hazard and Potential Status indices, we will take the outputs from the Ecosystem Status process (described above). We then load these outputs through the FIREHARM model to create a suite fire and fuel characteristics indices. We will use the assessment modeling statistics to create summarize the different characteristic indices into a few departure index for fire hazard and potential status. Again, LANDFIRE personnel will work directly with fire managers. Fire managers will evaluate the many products produced by FIREHARM to determine which ones help define a specific index important to management. An example of a Fire Hazard and Potential Status index could be a fire-fuel condition class, which would be based on key fire danger, fire behavior, and fire effects characteristics.

A complete description of these methods can be found in Appendix M.

Management Tools

Probably one of the most important parts of this project will be the ability to provide a series of management tools and publications that will allow managers to take full advantage of the LANDFIRE products. These tools need to be easy for the managers to use and understand. In addition, they need to be based on the best possible science. To complete this task we will provide the following:

1. A series of publications outline the methods and models used to develop all products. These publications will also be used to provide scientific credibility to the project.
2. The development of an interactive web page that will allow managers to download the data, tools, and general information about the project.
3. The development of a management toolkit, which will allow managers the ability to modify the classifications based on additional plot information or expert opinion, scale the data up to larger scale or step-down the data to a finer classification, and run the different models created for the projects.
4. A series of technology transfer workshops or classes, which will be used to educate the managers on all the data, tools, and models. These workshops will be helpful to the LANDFIRE staff in improving the interactive web page and management tool kit.

SCHEDULE

The LANDFIRE prototype is a three-year project starting in February 2002 and finishing in March of 2005. Intermediate components and products will be available starting in the fall of 2002. In this project, we will first develop methods and produce maps for mapping zone 16. We will then apply the methods to produce maps for mapping zone 19 (See Prototype Areas for a map). A complete schedule of the major task can be found in Table 6. During the project we will come-up with a scheduling estimates to create LANDFIRE products for the western US and conterminous US.

Table 6 – Schedule of LANDFIRE prototype important task and products. Were appropriate, the schedule has been broken down into Mapping Zone 16 and 19.

TASK ITEMS & PRODUCTS	2002				2003				2004				2005
	MAR	JUN	SEPT	DEC	MAR	JUN	SEPT	DEC	MAR	JUN	SEPT	DEC	MAR
Reference Database													
Development													
Load FIA Data		16			19								
Load Other Data		16	16	16	19	19	19	Both	Both	Both			
Release Database Version													
Ancillary GIS Layers	16	16			19	19							
Topography (DEMs)	16	16			19	19							
Soils	16	16			19	19							
Hydrology	16	16			19	19							
Biogeochemical Ecosystems					All								
Others	16	16			19	19							
Geo-Political	All	All											
Weather Climate Data													
DAYMET	All	All											
WXFIRE		16	16			19	19						
LF-BGC													
Development													
Model Runs		16	16			19	19						
Biophysical Setting (BS) Layer													
Creating Polygons		16	16			19	19						
Building BS Database		16	16			19	19						
Cluster Analysis of BS Database			16	16			19	19					
Creating BS Layer			16	16			19	19					
Assign BS Labels			16	16			19	19					
Creating PVT Layer				16				19					
Creating National BS Layer													

TASK ITEMS & PRODUCTS	2002				2003				2004				2005
	MAR	JUN	SEPT	DEC	MAR	JUN	SEPT	DEC	MAR	JUN	SEPT	DEC	MAR
Vegetation Classification (Key)													
Hierarchy	All	All	All			Ver 2							
Potential Vegetation Types (PVT)		All	All			Ver 2							
Cover Types (CT)		All	All			Ver 2							
Structural Stages (SS)		All	All			Ver 2							
Image Classification (Mapping)													
Pre-Processing Satellite Data	16	16	16		19	19	19						
Cover Types				16	16	16	16	19	19	19	19		
Canopy Closure				16	16	16	16	19	19	19	19		
Height Classes				16	16	16	16	19	19	19	19		
Structural Stages							16				19		
Successional Pathway Modeling													
Develop Pathways				All	All	All	All						
Preparing LANDSUM							16				19		
Historical Natural Fire Regimes (HNFR)													
Empirical Approach							16	16	16		19	19	
Expert System Approach							16	16	16		19	19	
Simulation Approach (LANDSUM)							16	16	16		19	19	
Create HNFR									16			19	
Fire Regime Condition Class (FRCC)													
Simulation Modeling (VDDT)									16	16			19
Statistical Analysis									16	16			19
Create FRCC									16	16			19
Fire Behavior Fuel Models (FBFM)													
Creating FBFM	All	All	All	All	All	All							
Assigning FBFM to PVT-CT-SS						All	All						
Mapping FBFM								16				19	
Fuel Loading Model (FLM)													
Summarizing Existing Database				All	All	All	All						
Statistical Assigning to PVT-CT-SS							All	All					
Mapping FLM								16				19	
FARSITE Data Layers													
Assigning Info to PVT-CT-SS							All	All					
Mapping FARSITE layers								16				19	
FIREHARM													
Creating the Model													

TASK ITEMS & PRODUCTS	2002				2003				2004				2005
	MAR	JUN	SEPT	DEC	MAR	JUN	SEPT	DEC	MAR	JUN	SEPT	DEC	MAR
Ecosystem Status													
Simulation Runs (VDDT)								All	All	All			
Management Indices Development									All	All			
Statistical Analysis to Create Indices									All	All	All		
Mapping Indices												16	19
Fire Hazard and Potential Status													
Running FIREHARM										All	All		
Management Indices Development										All	All		
Statistical Analysis to Create Indices										All	All		
Mapping Indices												16	19
Management Tools													
Development													
Technical Transfer													

COLLABORATION and PERSONNEL

The LANDFIRE project is a collaborative project between the scientists at USDA-FS Rocky Mountain Research Station, Fire Science Laboratory in Missoula, Montana and USGS EROS Data Center (EDC) in Sioux Falls, South Dakota. LANDFIRE will be supported by scientist at the USDA FS Pacific Northwest Research Station in Wenatchee, Washington; USDA FS Rocky Mountain Research Station, Forest Inventory and Analysis (FIA) in Ogden, Utah; System for Environmental Management in Missoula, Montana, and University of Montana in Missoula, Montana. Table 7 provides a list of task assignment for various people or institutions listed below.

Fire Sciences Laboratory Staff:

Lead Scientist: ***Robert Keane*** (USDA Forest Service) has extensive experience in ecological modeling and conducting large ecological field studies. Keane's responsibility will be to develop the methodology and scientific foundation needed for this project and to oversee the entire project.

Technical Project Manager: ***James Menakis*** (USDA Forest Service). Menakis will be responsible for the entire technical staff. He will ensure all GIS layers are developed with strict accuracy and quality controls, and he will coordinate the linkage of all GIS layers with the database and successional pathways.

Project Manager: ***Cameron Johnston*** (USDA Forest Service). Johnston will responsible for the overall management of the project. He will oversee and conduct all fiscal, personnel, and administrative tasks.

Fire Ecologist – Forestlands: (Position to be filled – GS-11/12). This person is responsible for creating and maintaining all successional pathways, fire regimes, and vegetation classifications for forestland communities.

Fire Ecologist – Rangelands: ***Melanie Miller*** (DOI Bureau of Land Management). Miller has extensive experience in fire ecology and plant succession in rangeland and shrubland communities. She will be responsible for creating and maintaining all successional pathways, fire regimes, and vegetation classifications for rangeland and shrubland communities.

GIS Specialist/Statistician: ***Lisa Holsinger*** (USDA Forest Service) Holsinger will be responsible for creating and maintaining the vegetation base layer. This includes assignment of PVT and biophysical setting classes to each mapped polygon. This person would also perform the statistical analyses to generate fire regimes and PVT for conterminous US.

GIS Specialist/Ecologists: ***Tom Thompson*** and ***Maureen Mislivets*** (USDA Forest Service). These people will be responsible for the development of all the GIS layers and will provide support to all staff members. Thompson will also be involved in maintaining all computer equipment used in this project.

Program Assistant: ***Karen Iverson*** (USDA Forest Service) – This person would attend to the day-to-day fiscal and budgetary tasks needed to implement a project of this magnitude.

Additional Fire Laboratory Support: ***Matt Rollins*** **–** Research Fire Landscape Ecologist; ***Russ Parson*** **–** GIS Specialist/Fire Ecologist; ***Eva Karau*** **–** GIS Specialist/Remote Sensing Specialist; and ***Alisa Keyser*** **–** GIS Specialist/Ecological Modeler.

EROS Data Center (EDC) Staff:

Lead Scientist: ***Zhi-Lang Zhu*** (USGS) **–** has the extensive experience in remote sensing and image processing vegetative and ecological attributes. Zhu's responsibility will be to develop the methodology and scientific foundation needed for this project at EDC.

Lead Remote Sensing Scientist: ***Chengquan Huang*** (USGS) **–** will be responsible for the development and coordination of all remote sensing products include Cover Type, Canopy Closure, and Height Classes.

Additional EDC Support: (3 to 4 additional remote sensing/imagine processing specialists and 1-fire ecologist/remote sensing specialists)

Cooperators:

FIA Ecologists/GIS Specialist – (GS 11 or 12) this person will be responsible in supporting all efforts and tasks at the Fire Science Laboratory; and facilitate the acquisition, application, and processing of FIA data.

Paul Hessburg (Research Pathologist at PNW) **–** Dr. Hessburg will perform the analysis that will develop the national biophysical settings layer.

Contractors:
This project will require the skills of a wide variety of privately employed ecologists, computer programmers, database managers, and ecosystem modelers. The following is a list of the institutions that we plan to involve in this LANDFIRE-US project.

Systems for Environmental Management Staff:

Database Manager: ***John Caratti* –** Caratti will be responsible for the developing, creating, and maintaining the Reference Database.

Database Technician: ***Jennifer Taylor:* –** Will be responsible for acquiring and loading the data into the Reference Database.

Programmer: *Larry Gangi* – Will be responsible for assisting with the development of LANDFIRE models, and conversation data into the Reference Database.

Biogeochemical Modeler: *Peter Thornton* – Dr. Thornton will be responsible for developing LF-BGC model and providing expert advise about the model through out the life of the project.

Fire Ecologists/Modelers: *Robert Burgan and Joe Scott* – Will be responsible for developing the new Fire Behavior Fuel Models.

Statistician: *Brian Steele* – Will be responsible for developing the statistical indices used to evaluate Ecosystem Status and Fire Hazard and Potential Status.

University of Montana Staff:

Numerical Terradynamics Simulation Group – This collection of skilled scientists and modelers will provide the DAYMET weather data.

Table 7 – Assignment of various people or institutions to specific LANDFIRE prototype tasks. Though not shown, Keane and Zhu are involved in all phases of the project directly relating to their teams.

TASK ITEMS & PRODUCTS	Keane	Menakis	Forest Eco	Miller	Holsinger	Thompson Mislivets	FIRELAB Support	EDC	FIA	Hessburg	Caratti Taylor	Gangi	Thornton	Burgan Scott	Steele	NTSG
Reference Database																
Development		■									■	■				
Load FIA Data									■		■					
Load Other Data											■	■				
Release Database Version											■					
Ancillary GIS Layers																
Topography (DEMs)					■	■		■								
Soils					■	■	■	■								
Hydrology					■	■										
Biogeochemical Ecosystems					■	■										
Others					■	■										
Geo-Political						■										
Weather Climate Data																
DAYMET		■														■
WXFIRE	■				■	■	■					■				
LF-BGC																
Development													■			
Model Runs					■	■	■									
Biophysical Setting (BS) Layer																
Creating Polygons		■			■	■	■	■	■							
Building BS Database		■			■	■	■		■							
Cluster Analysis of BS Database		■			■	■	■		■							
Creating BS Layer		■			■	■	■		■							
Assign BS Labels		■			■	■	■		■							
Creating PVT Layer		■			■	■	■		■							
Creating National BS Layer										■						

TASK ITEMS & PRODUCTS	Keane	Menakis	Forest Eco	Miller	Holsinger	Thompson Mislivets	FIRELAB Support	EDC	FIA	Hessburg	Caratti Taylor	Gangi	Thornton	Burgan Scott	Steele	NTSG
Vegetation Classification (Key)																
Hierarchy																
Potential Vegetation Types (PVT)																
Cover Types (CT)																
Structural Stages (SS)																
Image Classification (Mapping)																
Pre-Processing Satellite Data																
Cover Types																
Canopy Closure																
Height Classes																
Structural Stages																
Successional Pathway Modeling																
Develop Pathways																
Preparing LANDSUM																
Historical Natural Fire Regimes (HNFR)																
Empirical Approach																
Expert System Approach																
Simulation Approach (LANDSUM)																
Create HNFR																
Fire Regime Condition Class (FRCC)																
Simulation Modeling (VDDT)																
Statistical Analysis																
Create FRCC																
Fire Behavior Fuel Models (FBFM)																
Creating FBFM																
Assigning FBFM to PVT-CT-SS																
Mapping FBFM																

TASK ITEMS & PRODUCTS	Keane	Menakis	Forest Eco	Miller	Holsinger	Thompson Mislivets	FIRELAB Support	EDC	FIA	Hessburg	Caratti Taylor	Gangi	Thornton	Burgan Scott	Steele	NTSG
Fuel Loading Model (FLM)																
Summarizing Existing Database																
Statistical Assigning to PVT-CT-SS																
Mapping FLM																
FARSITE Data Layers																
Assigning Info to PVT-CT-SS																
Mapping FARSITE layers																
FIREHARM																
Creating the Model																
Ecosystem Status																
Simulation Runs (VDDT)																
Management Indices Development																
Statistical Analysis to Create Indices																
Mapping Indices																
Fire Hazard and Potential Status																
Running FIREHARM																
Management Indices Development																
Statistical Analysis to Create Indices																
Mapping Indices																
Management Tools																
Development																
Technical Transfer																

BUDGET

The budget for the prototype is estimated at 6 million dollars over three years, with the USDA Forest Service Rocky Mountain Research Station Fire Science Laboratory receiving 1.2 million dollars a year for three years; and DOI USGS EROS Data Center receiving $ 800,000 a year for three years. A first estimate of the prototype budget break down is shown in Table 8. During the prototype project will produce estimated costs for developing LANDFIRE products for the western US and conterminous US.

Table 8 – The budget estimate for the LANDFIRE prototype

Agency / Unit	Category	Costs in (1,000 of dollars)				
		02/01/02 09/30/02	10/01/02 09/30/03	10/01/03 09/30/04	10/01/04 02/01/05	Total
FIRELAB Fire Effects	Salary (FIRELAB)	160.0	275.0	275.0	60.0	770.0
	Salary (FIA)		67.0	67.0	17.0	151.0
	FIA Moving Costs		80.0			80.0
	Travel	20.0	30.0	30.0	10.0	90.0
	Supplies	35.0	25.0	25.0	5.0	90.0
	Equipment	120.0	30.0	30.0		180.0
	Software	40.0	20.0	20.0	5.0	85.0
	Building	120.0	5.0	5.0	1.0	131.0
	FIRELAB Sub Total	495.0	532.0	452.0	98.0	1,577.0
	FIRELAB Operating Costs @ 3%	14.9	16.0	13.6	2.9	47.3
	FIRELAB Unit Total	509.9	548.0	465.6	100.9	1,624.3
SEM	Reference Database	280.0	150.0	150.0		580.0
	LF-BGC Development & Maintenance	35.0	20.0	20.0		75.0
	Fire Behavior Fuel Models	100.0				100.0
	Indices Statistical Analysis		100.0			100.0
	WEB Development	20.0	10.0	10.0		40.0
	Management Tools			100.0		100.0
	SEM Sub Total	435.0	280.0	280.0		995.0
PNW	National Biophysical Settings	75.0	150.0	150.0		
RMRS (Including SEM & PNW) - Sub Total		1,019.9	978.0	895.6	100.9	2,994.3
RMRS Overhead @ 12 % (of 1.2 million)		144.0	144.0	144.0	12.1	444.1
RMRS (Including SEM & PNW)- TOTAL		1,163.9	1,122.0	1,039.6	113.1	3,438.4
EROS Data Center (EDC) - TOTAL		800.0	800.0	800.0		
LANDFIRE PROTOTYPE TOTAL:		1,963.9	1,922.0	1,839.6	113.1	5,838.4

DELIVERABLES

This project will result in several products that will be useful to managers in any agency with responsibility for fire management. Excepting the normal publication delays, all deliverables will be available at the conclusion of the study (spring 2005). Intermediate components and products will be available starting in the fall of 2002.

Table 9 is a list of how LANDFIRE products could be used adding the implementation of the National Fire Plan and the Cohesive Strategy. The LANDFIRE products include:

Digital databases consisting of:

- Historic Natural Fire Regimes
- Fire Regimes Condition Classes
- Biophysical Settings
- Potential Vegetation Types
- Cover Types
- Structural Stages
- FARSITE data layers
- Ecosystem Status
- Fire Hazard and Potential Status

Computer models for:

- Fire potential model (FIREHARM)
- Landscape simulations (LANDSUM)
- Biogeochemical model (LF-BGC)

Ancillary utilities and products:

- Comprehensive field plot database (Reference Database)
- A series of scientific publications
- Interactive website
- Tools allowing managers to scale the datasets
- Technology transfer

Table 9 – Potential applications of LANDFIRE products used to address Key Points in the National Fire Plan and Cohesive Strategy.

Priorities in the National Fire Plan and Cohesive Strategy	Potential Applications of a few LANDFIRE Products
Firefighting	The **FARSITE data layers** can be used to model fire spread.
Rehabilitation & restoration	The **Historic Natural Fire Regimes** and **Fire Regime Condition Class** data layers can help target these areas. **LANDSUM** can be used model treatment conditions into the future. **FIREHARM** could be used to evaluate these treatments.
Hazardous fuel reduction	The **FIREHARM** model and the **Historic Natural Fire Regimes** and **Fire Regime Condition Class** data layers can help target these areas.
Community Assistance	LANDFIRE will develop many layers that will be key for mapping the wildland/urban interface, but LANDFIRE will not create a wildland/urban interface map.
Accountability	LANDFIRE is being designed with the ability for affordable and efficient re-mapping every 10 years.
Improve the resilience and sustainability of forest and grasslands at risk.	The landscape simulation model **LANDSUM** and the **Potential Vegetation Types, Cover Types**, and **Structural Stages** layers can be used to understand these systems.
Conserve priority watershed, species, and biodiversity	Most layers and models developed by LANDFIRE can be used by other natural resource disciplines in targeting areas of concern.
Reduce wildland fire costs, losses, and damages	The **Historic Natural Fire Regimes** and **Fire Regime Condition Class** data layers and the **FIREHARM** model could be used to target watersheds of greatest concern.

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APPENDICES

Appendix A – Creating the Reference Database

Appendix B – Acquiring and Processing Ancillary GIS Layers

Appendix C – Methods and process for creating Biophysical Setting layers, using DAYMET, and running WXFIRE and LF-BGC models

Appendix D –Methods and process for creating Potential Vegetation Types map

Appendix E –Developing the Hierarchical Vegetation Classification (including Potential Vegetation Types Classification, Cover Types Classification, and Structural Stage Classification)

Appendix F – Image Classification used to create layers of Cover Type, Canopy Closure, and Height Classes.

Appendix G – Methods used to develop Successional Pathway Models

Appendix H – Methods used to modify and run LANDSUM

Appendix I – Creating Historical Natural Fire Regimes

Appendix J – Creating Fire Regime Condition Classes

Appendix K – Methods used to create Fire Behavior Fuel Models, Fuel Loadings Models, and FARSITE data layer inputs

Appendix L – Creating and running the FIREHARM model

Appendix M – Creating Ecosystem Status and Fire Hazard and Potential Status Index